JRC Scientific and Technical Reports

A Gas Pipeline model to support Critical European Energy Infrastructure Assessment

Russell Pride

EUR 23434 EN - 2008

EUROPEAN COMMISSION
Institute for the Protection and Security of the Citizen

The Institute for the Protection and Security of the Citizen provides research-based, systems-oriented support to EU policies so as to protect the citizen against economic and technological risk. The Institute maintains and develops its expertise and networks in information, communication, space and engineering technologies in support of its mission. The strong cross-fertilisation between its nuclear and non-nuclear activities strengthens the expertise it can bring to the benefit of customers in both domains.

European Commission
Joint Research Centre
Institute for the Protection and Security of the Citizen

Contact information
Address: European Commission - JRC
Via E. Fermi, 2749
I-21027 Ispra (VA)
ITALY

E-mail: russell.pride@jrc.it
Tel.: 0039 0332 78 6385
Fax: 0039 0332 78 5145

http://ipsc.jrc.ec.europa.eu/
http://www.jrc.ec.europa.eu/

JRC43013

EUR 23434 EN
ISSN 1018-5593

Luxembourg: Office for Official Publications of the European Communities

Printed in Italy

A Gas Pipeline Model to Support Critical European Energy Infrastructure Assessment

Author: Russell Pride

Abstract

Introduction

In the context of European Policy, in December 2005, the Council called upon the European Commission (EC) to make a proposal to develop a Directive on the identification and designation of European Critical Infrastructure (ECI). The original focus on terrorist threats later evolved into an all hazards approach. The severity of consequences and European dimension are to be assessed on the basis of Public, Economic, Environmental and Psychological effects, whilst owners/operators of ECI need to establish a “Sector” specific operator plan, including identification of assets, risk analysis and countermeasure prioritization. The EC is developing cross-cutting criteria to support the process of ECI identification on the basis of severity of consequences of disruption or destruction of the infrastructure. For the “Energy Sector” an improved understanding of the criticality of gas supply routes and infrastructure is desirable and it is anticipated that a model of the transnational gas pipeline network would assist in the process of assessing the usefulness of the cross-cutting criteria applied to this sector.

Building on previous work undertaken within the SARES Action, a methodology is being developed using detailed gas pipeline network modelling software to help identify elements of a network that may be considered to be critical. Gas has a key role in the energy supply future of the EC, with growth anticipated to rise from currently one fifth, to one third of total energy supply within the next 25 years, most of this increase for electricity generation. Up to 66% of gas may be derived from imports, these being essentially supplied through pipelines traversing the Russian Federation and the Commonwealth of Independent States, although an increasing quantity will be provided by sea transportation of LNG (Liquid Natural Gas). Market forces in general dictate what is commercially acceptable in terms of hardware infrastructure investment for meeting demands, but with an aging pipeline population the security and reliability of pipeline transmission gas supplies is seen as a key issue for Europe.

Pipeline models

Following a review of commercially available software for pipeline modelling a package from Advantica called SynerGee was purchased for evaluation. This can utilize underlying GIS pipeline route maps and hydraulically model all the key components of a pipeline system, from valves and regulators to storage fields and compressor stations. Some data previously collected for developing an Excel spreadsheet model “GENERCIS”, has been used to populate the model, but data from other sources such as Platts has provided the basic GIS background pipeline layout.

Current status

The Czech Republic was initially selected for compiling a demonstrator of the functionality of the approach. In addition, connecting networks and infrastructure were then introduced for the adjacent countries of Slovakia and Hungary. For all three countries the components of the Trans-National transmission pipeline network and the National high pressure network have been introduced into the model, but only generic details of items such as compressor stations and storage fields have been used. Following analysis of the model and assessment of its potential usefulness it was then demonstrated to the countries gas network operators in a workshop. The operators were generally supportive of the approach adopted and as a result more accurate details of the components may be made available through their subsequent completion of a questionnaire.

Conclusion

The development of a three-country gas network model using open-source data has been successfully demonstrated. The usefulness of the model in assessing cross-cutting criteria for the proposed European Directive on critical infrastructure may now be progressed.

Acknowledgement
The author would like to acknowledge the strong support and advice of Stanley Morris during the development of this work programme.

CONTENTS

Abstract.......... 3
1.0 Overall objectives.......... 3
1.1 Pipeline modelling software 3
1.2 Current status 3
2.0 Software requirements and selection.......... 4
3.0 Features of selected software - SynerGee 4
3.1 Facilities that can be modelled.......... 4
3.2 Basis of analysis 4
4.0 Pipeline diameters, operating pressures and flow properties 6
4.1 Diameters.......... 6
4.2 Operating pressures 6
4.3 Flow properties 6
5.0 Peak demand and cross-border flow rates 7
6.0 Compressor stations.......... 8
6.1 Driver units.......... 9
6.2 Compressor units.......... 9
6.3 Compressor stations & assemblies.......... 11
7.0 Country selection for developing a detailed model 11
8.0 Internal geographic distribution of demand based on population profile.......... 13
8.1 Peak demand and peak averaged winter demand 13
8.2 Daily gas demand 14
8.3 Domestic consumption and population distribution.......... 14
9.0 Storage facilities.......... 15
10.0 Production facilities.......... 16
11.0 Model construction.......... 17
12.0 Facility geographical location using Google Earth 20
13.0 Model analysis and initial results 23
14.0 Application to European Critical Infrastructure.......... 26
15.0 Presentation of model and initial results to pipeline operators.......... 26
16.0 Conclusions 27
17.0 References.......... 27
APPENDIX I : Software selection 28
APPENDIX II : Model settings used in simulations.......... 30
APPENDIX III : Pipeline internal diameter selection.......... 32
APPENDIX IV : Compressor station assemblies 35
APPENDIX V : Country pipeline mapping details 37
APPENDIX VI : Gas consumption and population data.......... 43
APPENDIX VII : Example reports from SynerGee.......... 48
APPENDIX VIII: Acronyms 50
APPENDIX IX : Support Information Requested from Operators 51

Definitions

The gas industry has traditionally used imperial units, so gas volumes are typically quoted in cubic feet, but there is a slow change to the SI system and the adoption of cubic meters for volume and Joules as a unit of energy. Pipe diameters are still usually quoted in inches and if quoted in mm, a convenient rounding-off is usually applied. Pressures are usually quoted in bar.

bcf = billions of cubic feet: note 1 billion = 10^9

bcm = billions of cubic meters = 10^9 m^3

Pj = Peta Joule = 10^{15} Joules

Tj = Terra Joule = 10^{12} Joules

Gj = Giga Joule = 10^9 Joules

Gross cv – total calorific value: a general value of 38MJ/m^3 has been assumed

Net cv – net calorific value

Mtoe = millions of tonnes of oil equivalent. (Conversions from Mtoe are based on a cv of 38Mj/m^3)

bar = 1.013 x 10^5 Pascals (N/m^2)

Hr = hour

List of Figures

Figure 1: Example of a typical compressor station layout selected for the Czech Republic 08
Figure 2: Fuel consumption profile for all compressor station drivers ………………………….. 09
Figure 3: Example of a full compressor map ……………………….………………………… 10
Figure 4: Typical compressor profile used in the current analysis …………….…………….... 10
Figure 5: Comparison between theoretical and real compressor data ………………………… 11
Figure 6: Key pipeline routes to Europe ………………………………………………………... 12
Figure 7: Pipeline infra-structure at higher resolution – from Platts …………………………….. 12
Figure 8: Gas load profile for the Czech Republic – year 2000 …………………………………. 13
Figure 9: European countries - annual gas load profile comparison …………………………… 14
Figure 10: Characteristic backpressure curves used in storage simulations …………………… 16
Figure 11: Detail of pipeline layout at a compressor station showing dimensions ……………… 17
Figure 12: Overview of modelled system for Czech Republic, Slovakia and Hungary ………… 18
Figure 13: Trans-National & high pressure transmission pipelines in the Czech Republic …… 19
Figure 14: Detail showing annotation of pipelines and nodes ……………………………… ….. 19
Figure 15: Key components in the model ………………………………………………………… 20
Figure 16: Example of a compressor station site from Google Earth…………………………….. 21
Figure 17: Example of a border crossing station from Google Earth…………………………….. 21
Figure 18: Bridge transmission pipeline crossing from Google Earth …………………………… 22
Figure 19: Geo-location of pipelines for compressor station compared with Google Earth …… 22
Figure 20: Locations of cross-border international transmission pipelines……………………… 23
Figure 21: Example model input/output pressures at compressor stations & country borders .. 25

Appendix III: Pipeline internal diameter selection

Figure A3.1: Effect on flow rate of pipeline wall thickness for various pipe diameters ………… 34

Appendix V: Country pipeline mapping details

Figure A5.1: Czech Republic pipeline model ……………………………………………………. 37
Figure A5.2: Slovakia pipeline model …………………………………………………………… 39
Figure A5.3: Hungary pipeline model …………………………………………………………… 41

Appendix VI: Gas consumption and population data

Figure A6.1: Population by region in the Czech Republic ……………………………………… 45

List of Tables

Table 1: Facilities & parameters that can be modelled within SynerGee ……………………….. 05
Table 2: Final selection of internal pipe diameters for different pipeline external diameters...... 07
Table 3: Comparison of basic gas facts for the 3 countries ……………………………………. 13
Table 4: Summary of flow rates to regions in the Czech Republic ……………………………… 15
Table 5: Data used for storage facilities …………………………………………….. …….. 15
Table 6: Country production and locations used in model ……………………………………… 17
Table 7: Flow rates and pressures assigned to cross-border points shown in Figure 17 ……… 24

Appendix I: Software selection

Table A1.1: Companies identified with possible software products ……………………………. 28
Table A1.2: Software requirements - assessed on a ranked basis ……………………………. 29

Appendix II: Model settings used in simulations

Table A2.1: Modelling parameters used in SynerGee …………………………………………… 30
Table A2.2: Common parameters used in compressor stations ………………………………… 30
Table A2.3 : Shapefile names with descriptions …………………………………………………. 30
Table A2.4: Base mapping layers ………………………………………………………………… 31

Appendix III: Pipeline internal diameter selection

Table A3.1: Preferred pipe sizes …………………………………………………………………. 32
Table A3.2: Class factors for de-rating pipelines ……………………………………………….. 33
Table A3.3: Final preferred pipe dimensions used in simulation ………………………………… 33

Appendix IV: Compressor station assemblies

Table A4.1: Driver/compressor combinations …………………………………………………… 35

Appendix VI: Gas consumption and population data

Table A6.1: Basic gas data for the Czech Republic ……………………………………………… 43
Table A6.2: Distribution of gas load between end users ………………………………………… 44
Table A6.3: Estimate of gas consumption by customer category ……………………………….. 45
Table A6.4: Population and gas consumption by region for the 3 countries ……………………. 46
Table A6.5: Calculation used for distribution of gas load in the Czech Republic ……………… 47

Appendix VII: Example reports from SynerGee …………………………………………………. 48

Appendix VIII: Acronyms …………………………………………………………………………… 50

1.0 Overall objectives

In the context of European Policy, in December 2005, the Council called upon the Commission to make a proposal to develop a Directive on the identification and designation of European Critical Infrastructure (ECI). The original focus was on the terrorist threat but this later evolved into an all hazards approach. The severity of consequences and the European dimension were to be assessed on the basis of Public, Economic, Environmental and Psychological effects, whilst owners/operators of ECI would need to establish a “Sector” specific operator plan, including identification of assets, risk analysis and prioritization of countermeasures. The European Commission is developing cross-cutting criteria to support the process of identification of ECI on the basis of severity of consequences of disruption or destruction of the infrastructure. For the “Energy Sector” an improved understanding of the criticality of gas supply routes and infrastructure is desirable and it is anticipated that a model of the transnational gas pipeline network would assist in the process of assessing the usefulness of the cross-cutting criteria when applied to this sector.

Building on work previously undertaken within the “Pipesecure” project within the SARES[1], VASTS and VATDIS Actions a methodology is being developed to use detailed gas pipeline network modelling software to help identify elements of a network that may be considered to be critical. Gas has a key role in the energy supply future of the EC, with growth anticipated to rise from currently one fifth, to one third of total energy supply within the next 25 years, most of this increase for electricity generation. Up to 66% of gas may be derived from imports, these being essentially supplied through pipelines traversing the Russian Federation and other CIS countries (Commonwealth of Independent States). There are also strong indications that an increasing quantity will be provided by transportation of LNG (Liquid Natural Gas) by sea. Market forces in general dictate what is commercially acceptable in terms of hardware infrastructure investment for meeting demands, but with an aging pipeline population the security and reliability of pipeline transmission gas supplies is seen as a key issue for Europe.

1.1 Pipeline modelling software

A decision was made at the start of the work to purchase steady state rather than dynamic analysis software. Successful dynamic modelling (hourly responses or less) is more likely to be dependent on detailed system knowledge that remains the focus of the pipeline operators themselves. Response times of interest in assessing critical infrastructure are more likely to be in the orders of days since total supply network lengths are often in excess of 7500km (from Northern Russia through to Central Europe a pipeline may pass through five or more countries) and a failure in the system at one end would take days rather than hours to propagate through to have an impact on supplies in Europe. Further, failure of a critical component may take weeks or months to rectify (the recent UK “Rough” storage field fire resulted in a four-month shutdown of the facility).

Following a review of commercially available software for pipeline modelling a package from Advantica called SynerGee was purchased for evaluation. This can utilize underlying GIS pipeline route maps and hydraulically model all the key components of a pipeline system, from valves and regulators to storage fields and compressor stations. Some data previously collected for developing an Excel spreadsheet model “GENERCIS”[2, 3] has been used to populate the model, but data from other sources such as Platts has been used to provide the basic GIS background pipeline layout.

1.2 Current status

The Czech Republic was initially selected for compiling a demonstrator of the functionality of the approach. In addition, connecting networks were then compiled for the adjacent countries of Slovakia and Hungary. For all three countries the components of the Trans-National transmission pipeline network and the National high pressure network have been introduced into the model, but only generic details of items such as compressor stations and storage fields have been used. Following analysis of the model and assessment of its potential usefulness it was demonstrated to the countries gas network operators and as a result more accurate details of the components may be made available to improve the functionality of the model.

2.0 Software requirements and selection

For the purposes of the development of a model that will cover not only the overall European gas pipeline infrastructure but also the routes from and through supply countries, it is considered that there are two key features that must be provided by the software as follows:-

- A Graphical Information System (GIS) – to provide a background capability of mapping pipelines and facilities.
- A powerful hydraulic analysis of the gas flows in the system including the capability to include system components such as compressor stations, storage fields and pipeline furniture.

A desirable third requirement was the capability to include a measure of risk and cost into the analysis. To meet these requirements a detailed search of commercially available software was undertaken and an analysis of their perceived attributes completed. Appendix 1 provides a listing of the products considered and a detailed list of the ideal requirements. Cost also played an important aspect in the final selection process that resulted in the software package "SynerGee being selected for evaluation.

3.0 Features of selected software - SynerGee

Background GIS or raster maps can be imported in various formats. In the case of pipeline maps, the best source of data identified was from the commercially available Platts' data base. The link to specific GIS co-ordinate systems (some 1700 options are available) enables the software to determine pipeline lengths directly from the background map.

Pipelines are modelled by dragging and dropping standard and user defined pipeline types from a "warehouse" onto the mapping area of the software. The pipelines can be configured to follow routes with a high precision. Similarly other facilities can also be added to the system. The connection point between pipelines or to other facilities is referred to as a Node, where the properties of the flow may be defined. Additionally, various options are available to modify pressures, flows or other more complex parameters for facilities such as compressor stations.

All facilities can be searched for, selected, displayed and/or labelled in various groupings. Constraints imposed when setting up various controls for some of the facilities can be switched between selected options enabling a solution to the flow equations to be obtained.

3.1 Facilities that can be modelled

The purchased software provides the capability of modelling a range of pipeline facilities, each with its own selected range of attributes. Table 1 shows the major parameters that have been used to date in model development, however there are further parameters that it is possible to include in future developments, some of which are particularly useful in assessing the overall performance of a complete network. Appendix II shows some of these parameters that can be set up and changed globally or through specific selection of facilities. Since the software is normally used by gas utilities each component may be modelled in considerable detail, including the control systems and limiting constraints on system performance. However such detail is usually only available to the operators themselves and for the current work many assumptions have had to be made in setting up the detail. For example in the case of compressor stations, theoretical models for both the drivers and compressors have had to be used.

3.2 Basis of analysis

SynerGee solves a set of simultaneous equations for each component in the system. It can deal with multiple and complex configurations simultaneously. SynerGee generates a node between each component in a system where the pressures and flows are calculated. By way of a simple example, flow through a pipe of known diameter may be defined and since it is conserved the pressure at one end must also be defined to calculate the pressure at the other end. Alternatively, the pressures at each end may be defined and SynerGee will solve for the flow. A further option

Table 1:
A selection of facilities & parameters that can be modelled within SynerGee

Facility	General					Physical data / Controls					Load / boundary conditions		Other	
Pipelines	Name	From & To Nodes	Flow equation	Reference flow & /or maximum pressure	Service state eg. proposed/ disabled	Outside/ inside diameter-wall thickness	Solve for diameter	Select specify length or calculate	Material	Efficiency	Flow rate	-	Tracing gas properties	Pipe character -istics
Storage fields	Name	From & To Nodes	Standard/ Methane desorption	Reference flow & /or maximum pressure	Service state eg. proposed/ disabled	Open flow coeffi-cient	Pressure drop exponent	Constraint interchange	Specify or solve for utilization	Utilization profile	Withdraw /injection boundary conditions & profiles	Inventory & hysterises	% draw-down	-
Valves & regulators	Name	From & To Nodes	Type (eg.) Manufact -urer	Reference flow & /or maximum pressure	Service state eg. proposed/ disabled	Open valve constant & profile	Close valve constant & close time	Constraint interchange	Set control mode	Set pressure & /or profile	-	-	-	-
Com-pressor stations	Name	From & To Nodes	Layout type	Reference flow & /or maximum pressure	Service state eg. proposed/ disabled	Fuel control node	Suction conditions	Constraint interchange control node	Specify or solve for utilization	Bypass valve properties	Flows & /or pressures	Compress-ion ratio	Select driver & compress-or options	Operation times

Notes
1: Parameters such as for gas properties, pipeline efficiency, etc. may be set globally.
2: In addition compressor stations can be configured with many combinations of drivers and compressors in a range of series parallel configurations coupled with cooler units and overall compressor station pipeline configurations. (See Section 6)

is that SynerGee solves for pipe diameter given the flow and pressures. Although at first it appears that nearly all the parameters need to be pre-specified, this is only the case at the extremities of the network or at some specific points within it. From this basis, there may be many hundreds of intermediate nodes and pipeline branches where the intermediate parameters are all subsequently calculated within the programme.

The full SynerGee software comprises many modules addressing specific issues for simulation of real time operations. For this analysis only the basic module was purchased, limiting analysis to steady state simulations, and although it is possible to introduce profiles of parameters related to time, each analysis is still steady state.

4.0 Pipeline diameters, operating pressures and flow properties

4.1 Diameters

Pipelines are usually referenced by their external diameter and these are often available. However, it is the internal diameter that determines the flow properties and this is the more important parameter for a hydraulic model analysis. The internal diameter is determined by the wall thickness that in turn is selected at the design stage to meet the required pressure regime the pipe is to operate within. Since such information is unlikely to be available in the public domain some assumptions have had to be made. Wall thickness for a given operating pressure regime is a function of the grade of the pipeline material and the operating pressure is further governed by the manufacturing process for the pipe.

4.2 Operating pressures

Finally there are further environmental factors that effect actual allowable operating pressures and these include such parameters as:-

- Distance of pipeline from various population or housing densities
- Distance of pipeline from buildings or areas with a specific function such as schools or hospitals
- Depth of pipeline
- Type of cover – eg. soil or concrete
- Operating temperature
- Degradation of pipeline due to corrosion
- Degradation of pipeline due to dents and gouges

There are many codes of practice and methods to determine the final operating pressures allowed and these are not harmonized across the many countries that supply or use gas in the European/Asian continent. Given the many uncertainties identified above, and without detailed information some simplifying assumptions have had to be used in selecting pipeline wall thickness. The result from these assumptions that are detailed in Appendix III is the following set of diameters given in Table 2 and used for all pipelines in the model. Where available data specifies diameter in integer inches the nearest integer metric diameter has been selected.

4.3 Flow properties

The actual flow of gas in a pipeline is determined by the internal surface roughness of the pipeline walls and the loss of pressure head as a result of bends for example, particularly at compressor, metering or regulator stations and obstructions in the pipeline, for example an orifice plate to measure flow rate. The overall flow loss may be represented by a loss in efficiency, a global parameter that has initially been set to 1. A change in the efficiency value forces SynerGee to recalculate the pressure drops in the system to retain the set flow rates.

Table 2:
Final selection of internal pipe diameters for different pipeline external diameters

Nominal external diameter		wall thickness	Internal diameter	Pipe grade	SMYS	Max. pressure
in	mm	mm	mm	X -	Bar	Bar
5.9	150.0	5.6	138.8	42.0	2,857.1	128.0
8.7	220.0	6.4	207.2	42.0	2,857.1	99.7
11.8	300.0	7.1	285.8	60.0	4,081.6	115.9
15.7	400.0	8.7	382.6	60.0	4,081.6	106.5
19.7	500.0	11.9	476.2	60.0	4,081.6	116.6
23.6	600.0	14.3	571.4	60.0	4,081.6	116.7
27.6	700.0	11.9	676.2	60.0	4,081.6	83.3
31.5	800.0	15.9	768.2	60.0	4,081.6	97.3
35.4	900.0	17.5	865.0	65.0	4,421.8	103.2
39.4	1000.0	19.1	961.8	65.0	4,421.8	101.3
47.2	1200.0	22.4	1155.2	65.0	4,421.8	99.0
55.1	1400.0	22.9	1354.2	80.0	5,442.2	106.8

SynerGee offers a range of flow modelling equations. An initial analysis of the various options led to the conclusion that in general the differences in predicted flow are generally small, with one or two exceptional equations indicating more significant variations, for example the Spitzglass equations. As a result a simplified Mueller equation for gas pipelines has been selected and in metric units gives the flow rate Q as seen in equation (i) below. This equation was also used in the GENERCIS[2, 3] model simulation. It should be noted however, that this equation does not require data on either surface roughness, friction factor or pipe altitude.

$$Q = 2.489 \times 10^{-9} \times E \times SG^{-0.425} \times D^{2.725} \times [(P_{in}^2 - P_{out}^2)/L]^{0.575} \quad \ldots\ldots\ldots\ldots\ldots \text{(i)}$$

Where:-

- Q = Flow rate (millions of m^3/hr - mm^3/hr)
- E = Efficiency
- SG = Specific gravity of the gas
- D = Internal pipeline diameter (mm)
- P_{in} = Inlet pressure (Bar)
- P_{out} = Outlet pressure (Bar)
- L = Pipeline length (km)

[Note that the use of the Mueller equation has been questioned by the software suppliers – see section 13.0]

5.0 Peak demand and cross-border flow rates

Data collected during the development of the GENERCIS Excel spreadsheet model has been used to provide the maximum cross-border pipeline flow rates (in mm^3/hr) used in the SynerGee model. Since pressure data for pipelines is not available and has to be assumed, a sensitivity analysis has to be used to help understand the importance of supply pressures. All the remaining flow rates and pressures are calculated within the model. Flow rates used for peak demand within the country are quoted as hourly but are typically in the order of 1/24 of daily flow rates based on an analysis of peak demand as discussed further in Section 8. Hence the model may be considered to represent a worst case peak winter demand simulation. A limitation at present is that since not all countries have a peak demand at the same time, cross-border flow rates need not necessarily be at their maximum level. Further discussion on this issue will be found in a previous report[3].

6.0 Compressor stations

SynerGee provides facilities for detailed modelling of compressor stations, but the required detailed information found to date in the open literature has been very limited. A compressor station may comprise a number of driver/compressor assemblies in either series or parallel combinations and these are linked through cooling units and to each other in various optional station pipeline layout arrangements. Due to lack of information parallel operation of units was assumed as shown in Figure 1, but series/parallel operation is possible. In the Czech Republic up to 10 driver/compressor sets may be employed in a single station providing flexibility in matching required demand. Power ratings and number of driver/compressor units for each of the six compressor stations were available for the Czech Republic and this data has been included in the model. A total capacity of 351MW is available from 51 sets with typical compression ratios of 1.2 to 1.3.

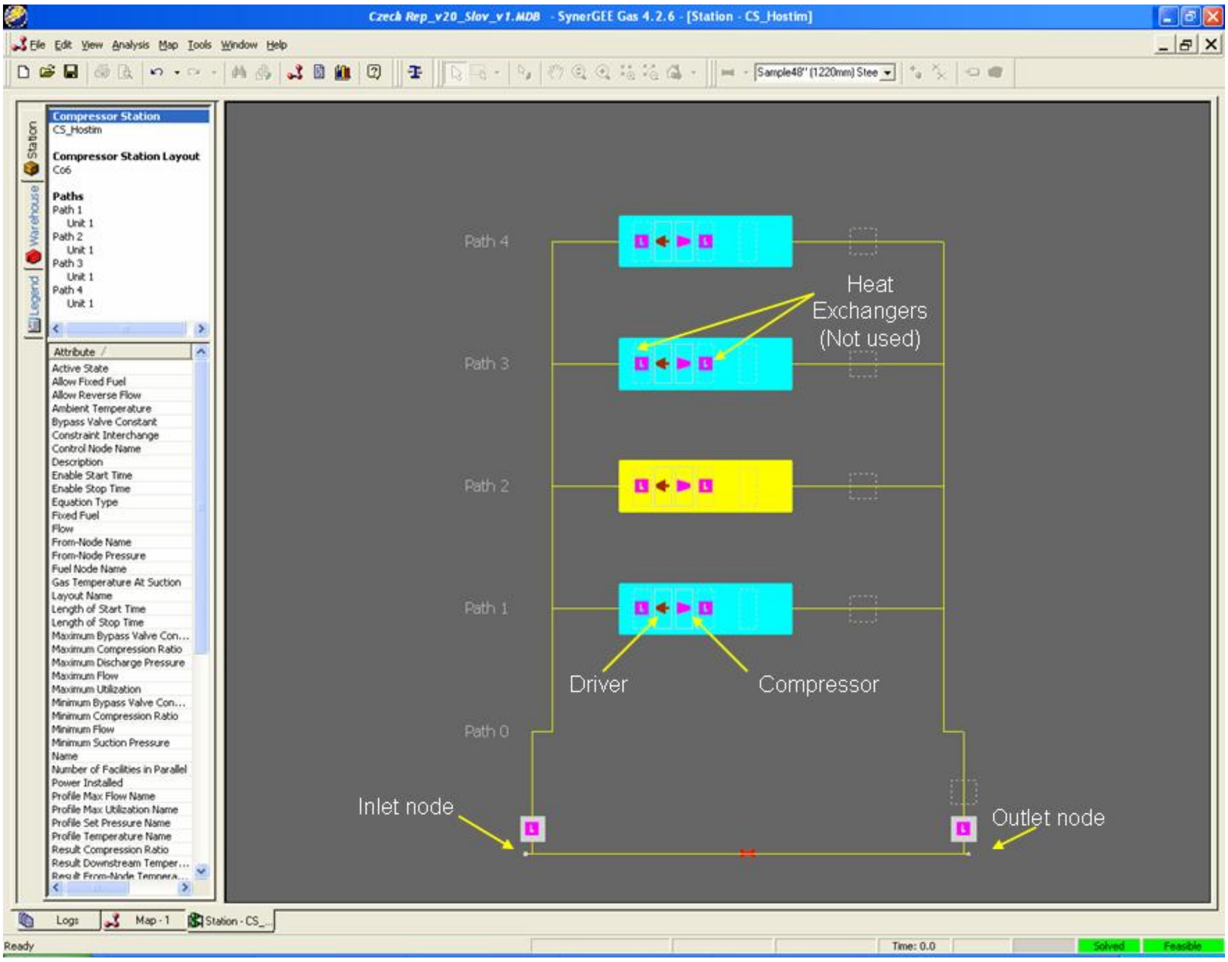


Figure 1: Example of a typical compressor station layout selected for the Czech Republic

Control of operation may be based on supply or demand pressures selected at various points in a network. The outlet node of the station was selected in all cases. SynerGee provides for analysing a range of engine or turbine drivers and compressors in a wide variety of combinations, including modelling a detailed compressor map. However, due to the limited available data it was practical to select nominal theoretical models for both driver and compressor units. Similarly, no data was available on the use of cooler units or station site pipeline pressure losses, so at present these have been excluded from the model. Again it is possible to include “yard” pipeline losses as fixed values for each station and other variable losses associated with the suction and discharge pressures or the staging of the compressors. For the model a constant value of 0.3bar was selected for both the suction and the discharge sides. Until further knowledge is obtained about possible additional equipment such as coolers or pulsation dampers, etc. no further loss factors have been included at present.

6.1 Driver units

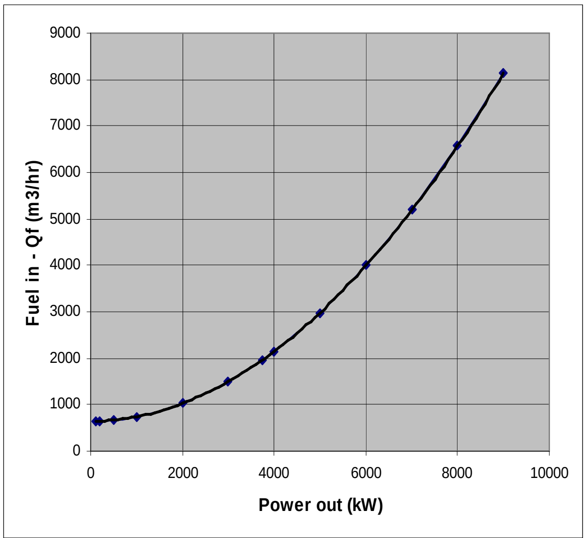
Drivers may be electrically operated or more usually use gas fuelled directly from the pipeline network with either gas engine or turbine options available for modelling. For this simulation fuel gas was taken from the inlet node to the station and a "Theoretical Driver" from the SynerGee option list was selected. The same fuel consumption profile was assumed for all station driver units as shown in Figure 2, the data for the polynomial fits being taken from an example provided in the SynerGee support documentation for a 5000hp (3.75MW) compressor unit. The fuel consumption profile was then scaled for different known unit sizes, typically in the range from 6 to 23 MW as found in the Czech Republic.

The fuel consumption equation (ii) in metric units is of the form:-

$$Q_{fuel} = C_2\,P_{out}^{\,2} + C_1\,P_{out} + C_0 \quad \ldots\ldots\ldots\ldots\ldots\ldots \text{(ii)}$$

Where Q_{fuel} is the fuel flow rate in mm^3/hr, and P_{out} is the outlet Power in kW and the coefficients are given as:-

C_0 = 638.4166 m^3/kW-hr/kW
C_1 = 0.013437 m^3/kW-hr
C_2 = 0.000091 m^3/kW-hr-kW



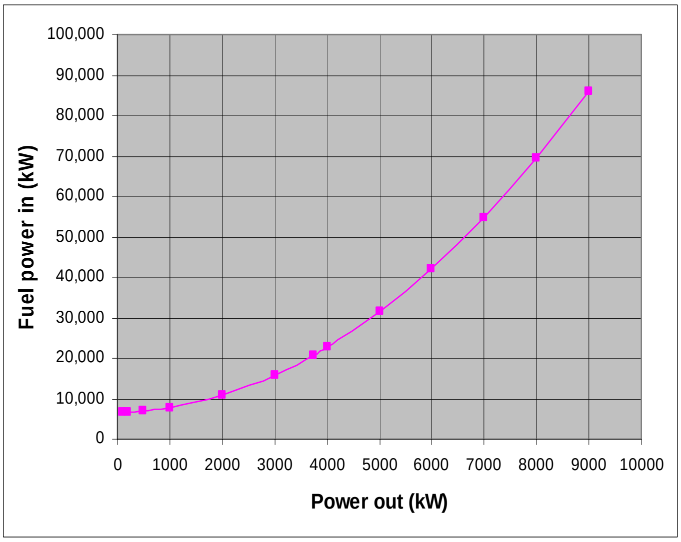


Figure 2: Fuel consumption profile used for all station drivers

6.2 Compressor units

Both rotary and turbine compressors may be modelled in considerable detail if data is available. For example a full turbine compressor map, as shown in Figure 3, could be modelled.

Available data on the Czech Republic indicates that all compressors are most likely to be centrifugal units, therefore for the current analysis all compressors were modelled using the SynerGee "Actual Power/Flow theoretical form" centrifugal unit model using the same equation and coefficients as given in equation (iii) below.

$$P = Q_s \times Z \times [K_1 \times (P_d/P_s)^{K_3} - K_2] \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(iii)}$$

Where:-

P is the output power in kW
Q_s is the flow rate in millions of cubic meters per hour (mm^3/hr)
P_d is the absolute discharge pressure in bar

Ps is the absolute suction pressure in bar
Z is the gas compressibility factor (taken as 1)

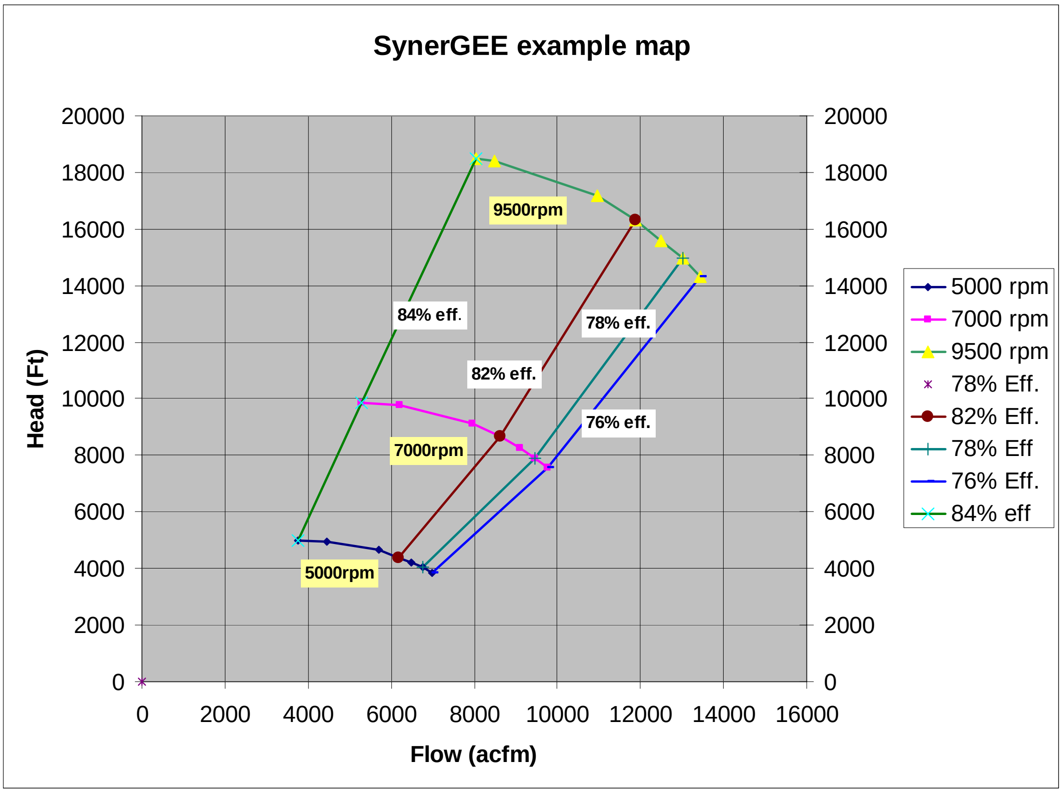


Figure 3: Example of a full compressor map (shown in Imperial units) that could be modelled within SynerGee if full data is available

Values for the “K” coefficients were taken again from the SynerGee literature example and in metric units are as follows:-

K_1 = 121927.1 kW/m^3/hour
K_2 = 121663.5 kW/m^3/hour
K_3 = 0.231 [ratio of {(n-1)/n} where n is the polytropic exponent = 1.3]

An example from SynerGee of flow rate versus differential pressure (dP) for a real compressor is shown in Figure 4.

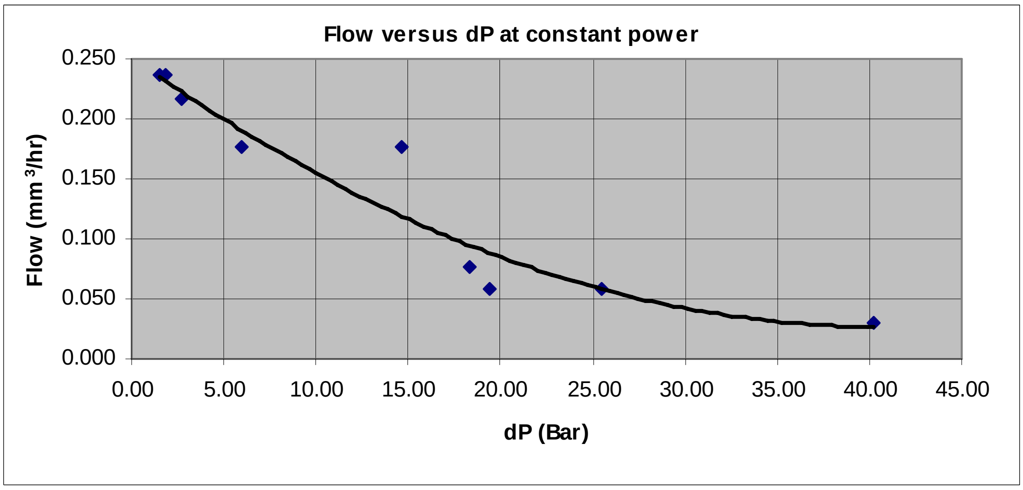


Figure 4: Example compressor flow profile used in the current analysis (Data from SynerGee for a 4kW compressor).

Figure 5 compares the real data with the theoretical form. SynerGee has the option to compensate the theoretical fuel consumption below a certain minimum power by addition of a correction factor, improving the low power correlation. Using an example from SynerGee a value of 500kW has been used in these initial models. SynerGee input data required includes the maximum power output and the fuel requirement at minimum power and optionally various other control parameters including a maximum compression ratio.

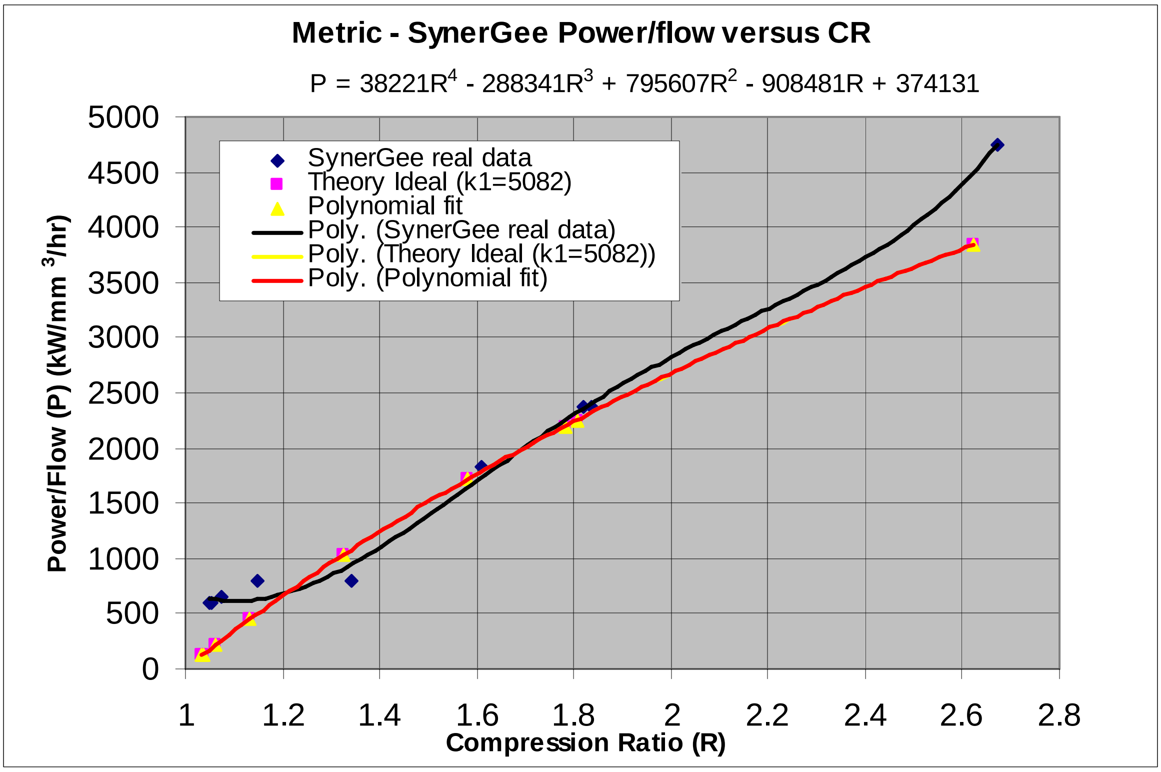


Figure 5: Comparison between theoretical and real compressor data

6.3 Compressor stations & assemblies

SynerGee enables combinations of driver/compressor to be quickly installed into compressor station paths. Appendix IV shows the combinations used in the current model. The location of the actual compressor stations is provided later in further detail for each country in the maps shown in Appendix V and in diagrammatic form in the results Section 13.

7.0 Country selection for developing a detailed model

Figure 6 shows the main gas flow routes through Europe. Current routes are colour coded in red and planned /enhanced or under construction in blue.

Figure 7 shows in addition and in greater detail the high pressure gas pipelines in each country.
The Czech Republic is one of the major current transit routes but also has a limited internal high pressure pipeline infrastructure, making it a good choice for constructing a detailed model with minimum complexity. In addition, to provide linked infrastructure, the neighbouring countries of Slovakia and Hungary, where there is more detailed national pipeline routing available, have been included together with the supply routes of the transit pipelines from Ukraine and to Germany and Austria respectively. By comparison with the Czech Republic, Table 3 shows the main gas facts for Hungary and Slovakia. The basic modelled pipeline infrastructures for each country are shown in more detail in Appendix V.

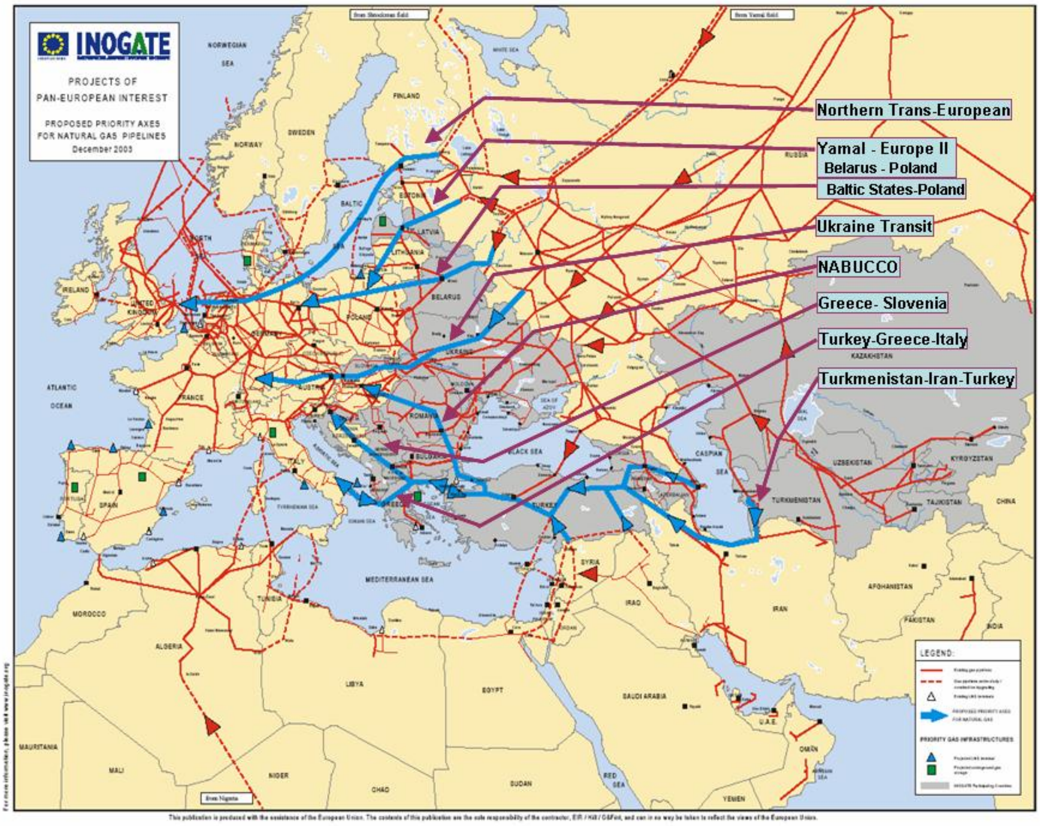


Figure 6: Key pipeline routes to Europe

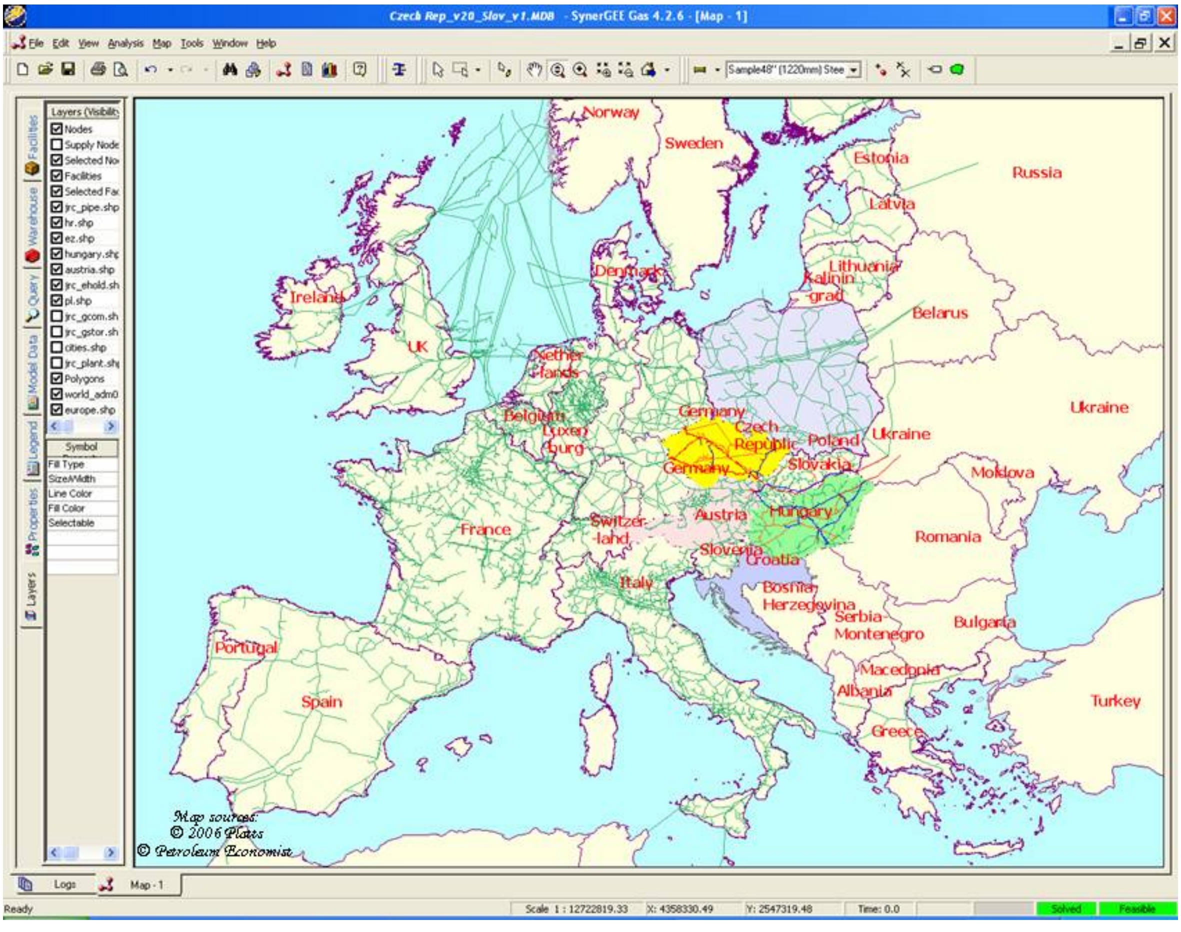


Figure 7: Pipeline infra-structure at higher resolution – from Platts

Table 3:
Comparison of basic gas facts for the 3 countries

Country		Source - Eurogas 2005 (Gross PJ)							Calc.
		Consumption					Production	Import	Export
		Domestic	Industrial	Power	Other	Total			Gross PJ
Czech Republic	CZ	192	155.1	7.3	0	354.4	4.8	356.6	7
Hungary	HU	292.7	85.5	146.1	38.3	562.6	108.4	454.2	0
Slovakia	SK	84.5	80.4	46.5	25.9	237.3	3.6	260.7	27

8.0 Internal geographic distribution of demand based on population profile

The gas demand profile for a typical country comprises a mix of internal national demands and a requirement to import and export transmission gas through the country. Overall system flows and pressure drops will therefore also depend on the size and location of the internal demands, the domestic demand from the transmission system and available internal supply sources and storage facilities. To model such detail would require an enormous amount of gas distribution data that would be far to complex to consider at a pan-European scale so it was considered necessary to use a simpler approach to provide a representative domestic gas demand profile across an entire country. Appendix VI details the strategy adopted that is summarized in the following sections.

8.1 Peak demand and peak averaged winter demand

Gas demand meets domestic, commercial, industrial and power requirements. Some demand is constant and some is a function of temperature. Winter demand is always greater and there is usually a particular peak consumption day that is met from short-term local storage facilities such as line pack. Figure 8 shows the annual profile for the Czech Republic[4], with the peak demand occurring in January, a base load of about 40% and variable load of 60% of annual.

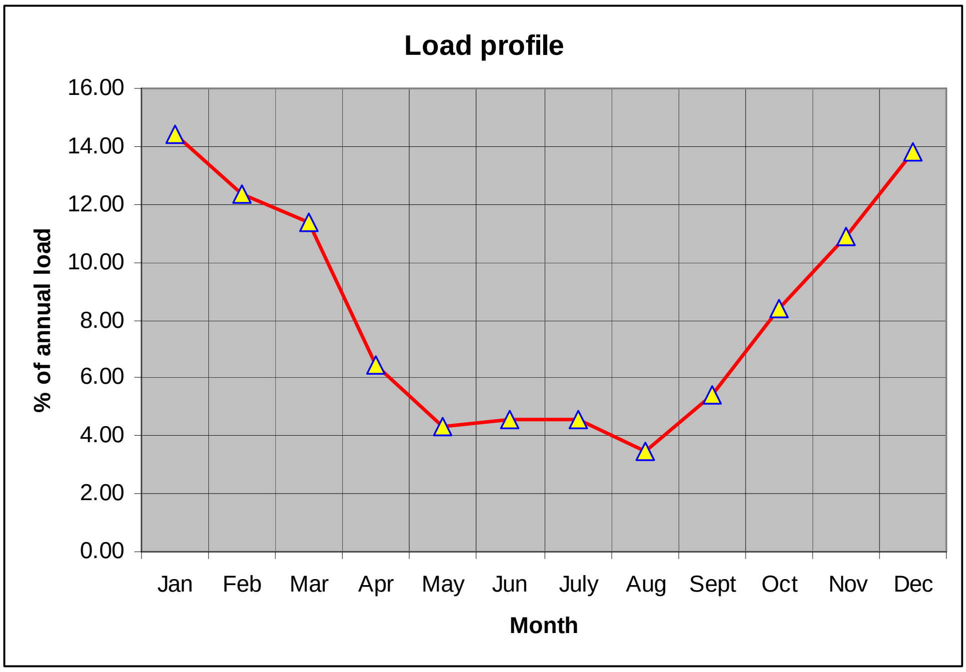


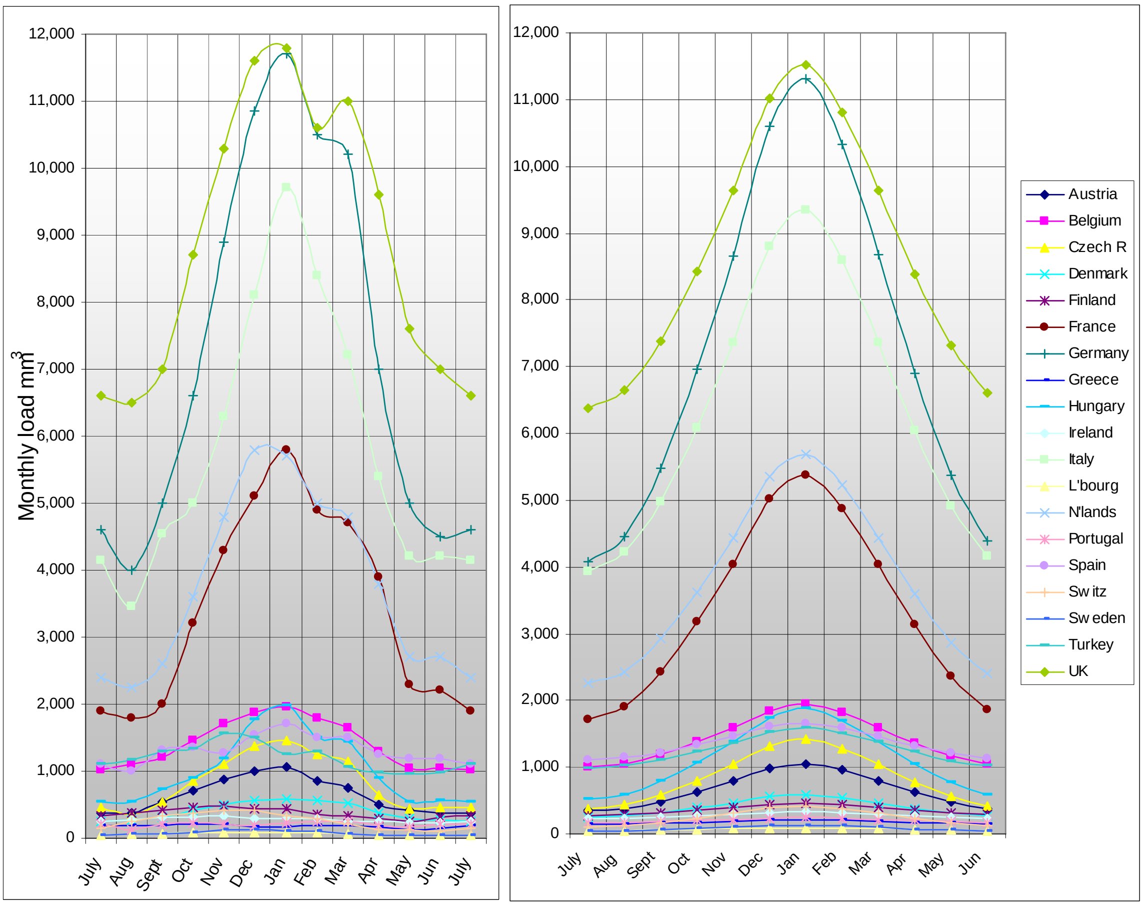
Figure 8: Gas load profile for the Czech Republic – year 2000

There is a great deal of similarity in such a profile for most European countries as shown in Figure 9 where both original data and normalized monthly polynomial fits are represented.

For the model it is assumed that a failure in the critical infrastructure would result in a potential several week reduction in availability of supply, so it was more appropriate to select an average peak winter demand that may exist over a limited time period rather than just the peak demand. A value for this is derived in Appendix VI.

8.2 Daily gas demand

The SynerGee model is based on hourly flow rates hence the selection of the time that gas is supplied to end users is critical to the interpretation of the model results. Simply dividing the peak January demand by the number of hours in the month will not provide a representative value of flow rate. Hence consideration must be given to the time different types of user need supplies and their required daily demand profiles. Appendix VI discusses this issue in greater detail, but it is clear that this is one of the critical parameters effecting overall flow rates that may vary by up to a factor of perhaps two. The consequence of this is that more units in compressor stations will be required to maintain flow rates and system pressures and worst case scenarios need to be explored. In the first model build the gas profiles have been based on a daily joint domestic and power production consumption of 16 hours and an industrial/other consumption



Original data Figure 9 Polynomial data fits
European countries - annual gas load profile comparison

using a mix of 60% 16 hour and 40% 24 hour demand profiles (option 2 detailed in the appendix). This is probably one of the most important parameters in determining the criticality of the model and requires further detailed specific knowledge of the network system.

8.3 Domestic consumption and population distribution

The calculated hourly peak winter average demand has been distributed proportionately throughout the country, based on population distribution by region and through the known key off-take points in the internal high pressure distribution systems and where known, their available peak flow rates. Table 4 below summarizes, by way of example, the final flow rates by region for the Czech Republic.

Table 4: Summary of flow rates to regions in the Czech Republic

Region name	Population	Dwellings	Consump.(mm³)/hr/region		Total flow	No. of offtakes
	No.	No.	Domestic	Ind.	Dom+Ind	
Severomoravsky	1,948,344	774,171	0.299	0.140	0.438	7
Jihomoravsky	2,041,856	816,268	0.315	0.147	0.462	7
Vychodocesky	1,230,332	530,550	0.205	0.096	0.300	9
Stredocesky	1,124,166	497,708	0.192	0.090	0.282	8
Praha	1,171,873	550,909	0.212	0.099	0.312	5
Jihocesky	699,326	699,326	0.270	0.126	0.396	4
Zapadocesky	857,760	370,072	0.143	0.067	0.209	7
Severocesky	1,173,847	509,414	0.196	0.092	0.288	9
Totals	**10,247,504**	**4,748,418**	**1.831**	**0.856**	**2.687**	**56**

Further details of the process in determining these are given in Appendix VI together with equivalent results for Hungary and Slovakia. For the Czech Republic, where there is no underlying mapping for final supply off-takes the diameters have all been set at an arbitrary 300mm and an undefined length, typically in the range 5 to 10 km. It is then assumed that a regulator station will determine downstream pressures, etc. In the case of Hungary, where many more off-takes were identified, these were set at 220mm diameter – a figure given within the Platts data set. In the case of Slovakia, there was sufficient pipeline infrastructure available from the Platts database, including diameters, to be able to allocate loads to each pipe that had a termination point. In all cases however, additional off-takes may exist reducing downstream pipeline loading.

9.0 Storage facilities

Storage field data available for the three countries used in the simulation is provided in Table 5 below. The maximum hourly rates are assumed to be in direct ratio to the maximum day rates obtained from several web sources and the ERGEG report[5]. Extraction rates of gas from a gas field are a function of the field properties which are not known. SynerGee uses a back-pressure simulation to calculate flow rate based on equation (iv) below.

Table 5: Data used for storage facilities

Data source	Country	Region	Store type	Node No.	Store Name	Working capacity	Delivery Rates		C_O
							Max.	Actual	value
						mm³	mm³/hr		
IEA 2002	Czech Republic	Jihomoravsky	Field	NCj26	Uhrice	100	0.25	0.249	12500
				NCj15	Dolni Dunajovice	700	0.50	0.500	25000
				NCj21	Tvrdonice	487	0.29	0.29	14500
		Stredocesky	Field	NCa26	Haje	57	0.25	0.22	12500
		Severomoravsky	Field	NCs02	Tranovice	228	0.10	0.1	5000
				NCs06	Stramberk	435	0.25	0.249	12500
			Aquifer	NCs12	Lobodice	140	0.13	0.128	6369
		Totals				2147	1.77	1.74	-
HEO 2006	Hungary	Bacs-Kiskun	Field	NHa22	Zana-Nord	1300	0.88	0.826	45000
		Hajdu-Bihar		NHm12	Hajduszoboszlo	1590	0.80	0.749	55000
		Zala		NHz05	Pusztaederics	330	0.11	0.108	5300
		Bekes		NHd10	Kardoskut	240	0.10	0.086	5500
		Csongrad		NHc13	Maros-1(Algyo?)	150	0.09	0.085	4500
		Totals				3610	1.98	1.85	-
Ten -e Oct.05*	Slovakia	Zapadoslovensky	Under-ground	62	Lab	2000	1	0.977	26000

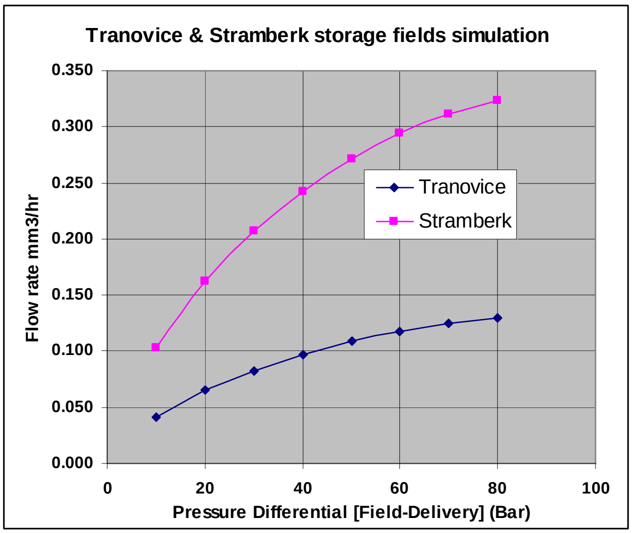
* NOTE: It is known that the "Lab" store in Slovakia is leased to the Czech Republic. The pipeline route also feeds many other off-takes in Slovakia. The known input flow rate of 0.2mm^3/hr to the Czech Republic has been created via the Mokry PS entry point (Node NSe62) by adding a short length of reduced diameter pipe to restrict flow rate. To create the lab store flow rate it was necessary to increase n=0.8.

$$Q = C_o \times F \times (P_f^2 - P_d^2)^n \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(iv)}$$

Where:-

Q = Flow rate (mm^3/hr)
C_o = Open flow capacity coefficient (mm^3/hr/Bar^2)
F = Field utilization coefficient (Considered as an input of 1)
P_f = Field shut-in pressure (Bar)
P_d = Delivery pressure (Bar)

In order for SynerGee to calculate an "Actual" flow rate it was necessary to select values for the field shut-in pressure and open flow coefficient. Values of 100 bar and 0.7 were chosen respectively leading to a representative curve for the Tranovice and Stamberk storage fields as is shown in Figure 10. The gradient of 0.7 and the log intercept of 8.5172, leads to a C_o value of 5000 in the case of the Tranovice field and the actual flow rates shown in Table 5 computed within SynerGee for the remaining fields. For the Slovakia Lab store it was necessary to raise n to a value of 0.8 to achieve flow rates at reasonable pressures and the reason for this requires further investigation.



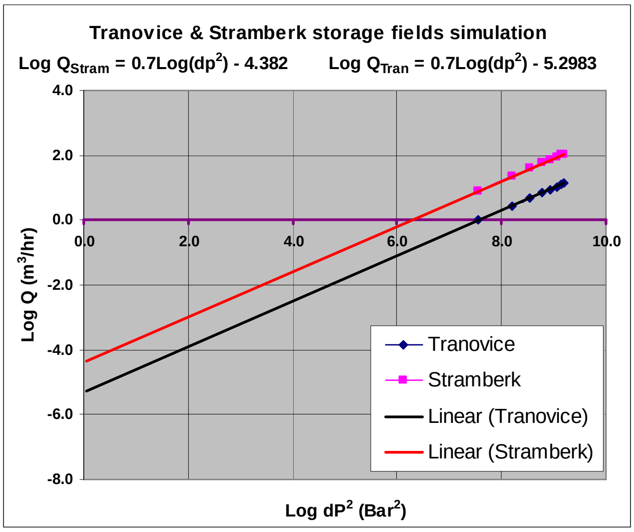


Figure 10: Characteristic backpressure curves used in storage simulations

10.0 Production facilities

Production of natural gas in two of the three countries considered is very limited (see Table 6) and the geographical locations have currently not been identified. However, Hungary has a substantial production capacity of 2.93bcm and the Petroleum Economist map identifies 7 major gas processing plants, but the distribution of this load and specific locations of the plant have currently not been identified. In order to take some account of flow rates the following assumptions have been made.

1) Hourly flow is simply the annual production divided by the number of hours in the year (8750 hours)
2) For the Czech Republic a location near to the store at Stramberk was selected.
3) For Slovakia the contribution was added near to the single storage facility at Láb.
4) For Hungary the contribution was divided equally between locations close to the five storage facility locations.

Table 6: Country production and locations used in model

Country	Production per year (from Eurogas 2005 data)		Flow mm^3/hr	Arbitary number & production locations chosen for model
	PJ	As % of annual consumption		
Czech Rep	4.8	1.4	0.01441	1 near Stramberk
Hungary	108.4	19.3	0.32545	The 5 storage fields each of 0.065
Slovakia	3.6	1.5	0.01081	1 near Láb

11.0 Model construction

The GIS model was constructed by overlaying SynerGee pipelines (by dragging and dropping from a warehouse portfolio) onto the underlying Platts' pipeline layout. The Platts' database provides outside pipeline diameter information and also the geographical location of gas storage sites and compressor stations. The Platts' database was used in preference to the Petroleum Economist database since the latter pipe locations were considered to be more symbolic rather than actual. Even so, the Platts' layout has to be symbolic when it comes to the detailed location of pipelines, particularly at multiple pipeline connections or at compressor stations as indicated in Figure 11 where it can be seen that a typical dimension between multiple pipelines is 154m. This will often be significantly larger than in practice.

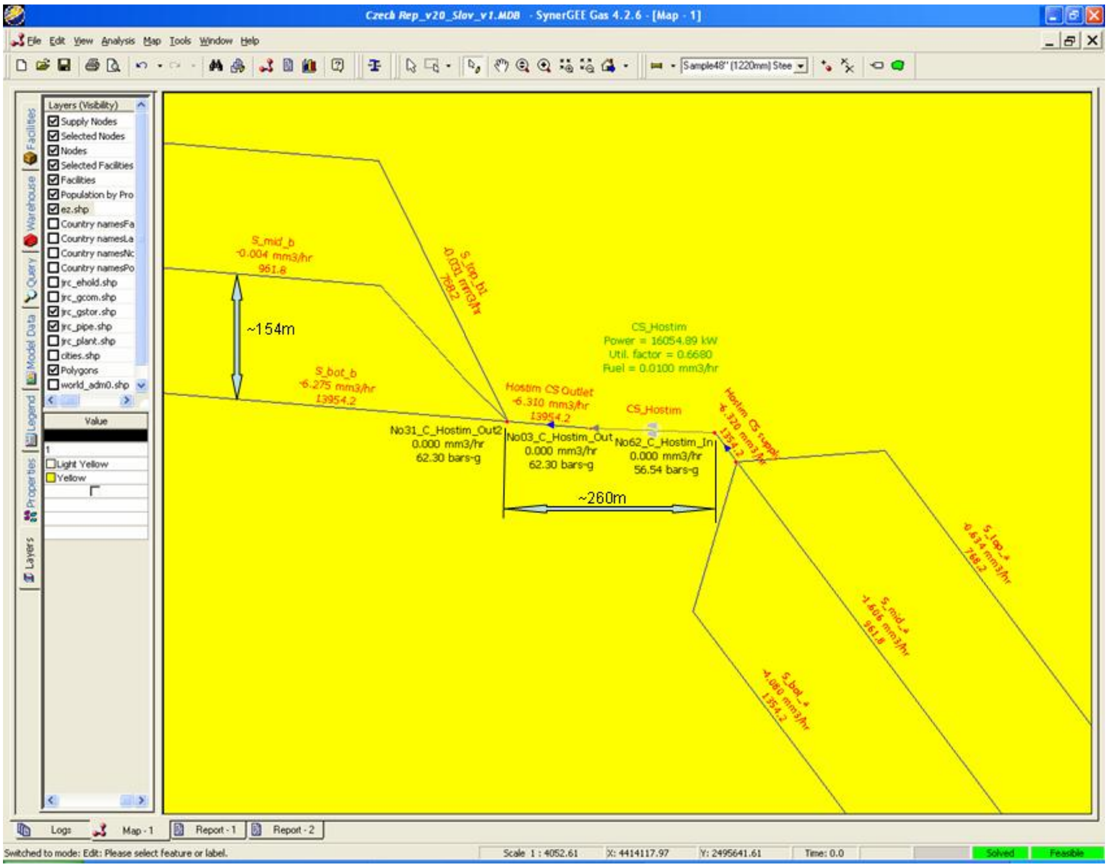


Figure 11: Detail of pipeline layout at a compressor station showing dimensions

The process of replicating pipelines was slow since the approach was first to approximate the mapping of the pipeline route at low resolution (typically with a replication accuracy compared to the underlying Platts model pipelines of up to 300m) and then follow this by a high resolution placement resulting in a replication of the original Platts' layout to the order of 1 to 2 meters. The

SynerGee pipelines have been colour coded according to diameter, but many other options are available – for example flow rate.

As each pipeline or facility is added it is assigned its' physical and operating properties and between any changes in properties SynerGee introduces a Node. As each pipeline or facility was added to the map a full flow analysis of the system was conducted. This approach was adopted because SynerGee solves multiple simultaneous equations for each facility in the system and it only requires one iterative failure for the whole system to produce multiple errors which then propagate through the system producing many error messages that cannot be easily traced to specific components and locations in the system. One uncertainty in compiling the network is whether some pipelines shown in the Platts' database as crossing are actually connected at that point. Where there was some doubt a connecting node was introduced. A further issue is that where multiple pipelines cross at a known compressor station location, it is not known which pipelines are located on the up or down-stream side, and indeed if they are all subject to pressure rises.

SynerGee does offer the opportunity to replicate an entire base map in a single operation; the entire Platts model includes over 7000 pipelines; however, the result during analysis was found to produce multiple error messages that could not be located to specific features. There is an additional software module that has not been purchased, that enables this activity to be subdivided which may resolve the issue and would be particularly useful if the analysis is extended to a full European model. Figure 12 shows an overview of the pipelines modelled in the three countries. The flow directions determined during the SynerGee analysis are indicated by arrows. Functioning compressor stations are shown in blue, a non-functioning facility could be shown in red. Appendix V provides further detail of the pipelines for each country.

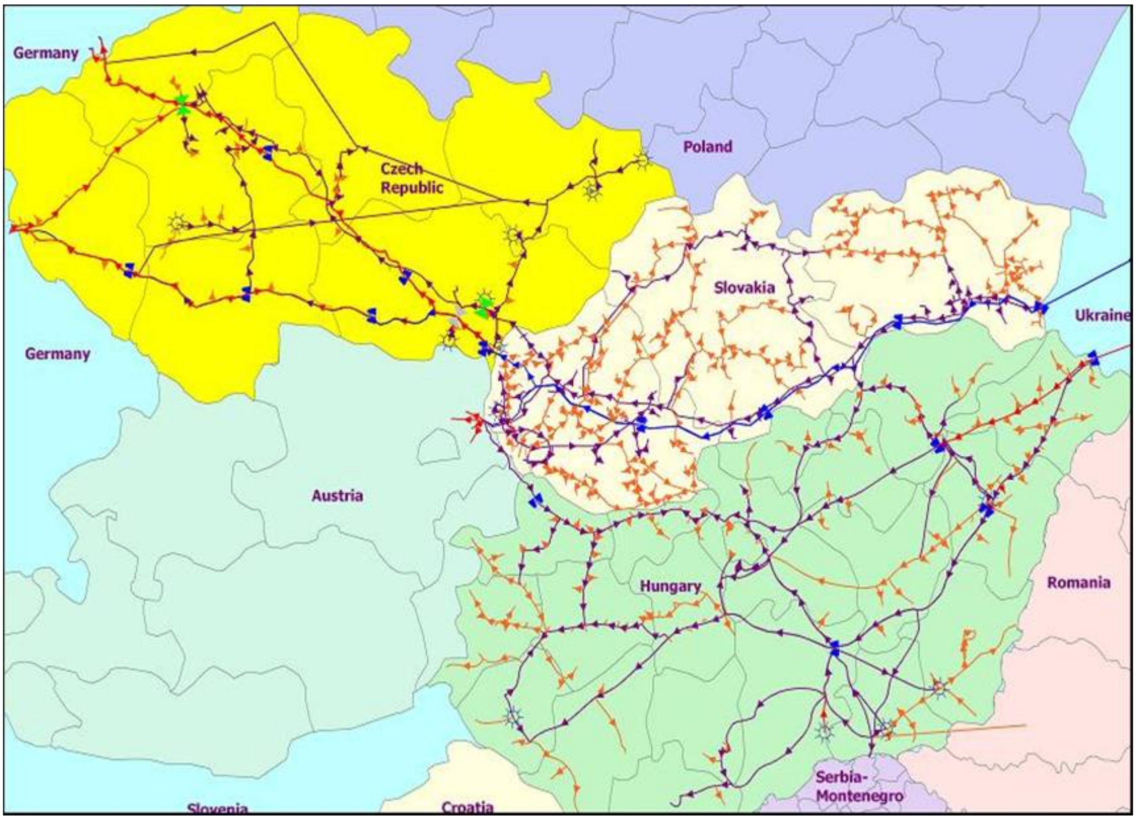


Figure 12: Overview of modelled system for Czech Republic, Slovakia and Hungary

Figure 13 shows the Czech Republic pipelines in greater detail and includes the administrative regions (grey boundaries) used for determining population distributions when calculating regional gas loads.

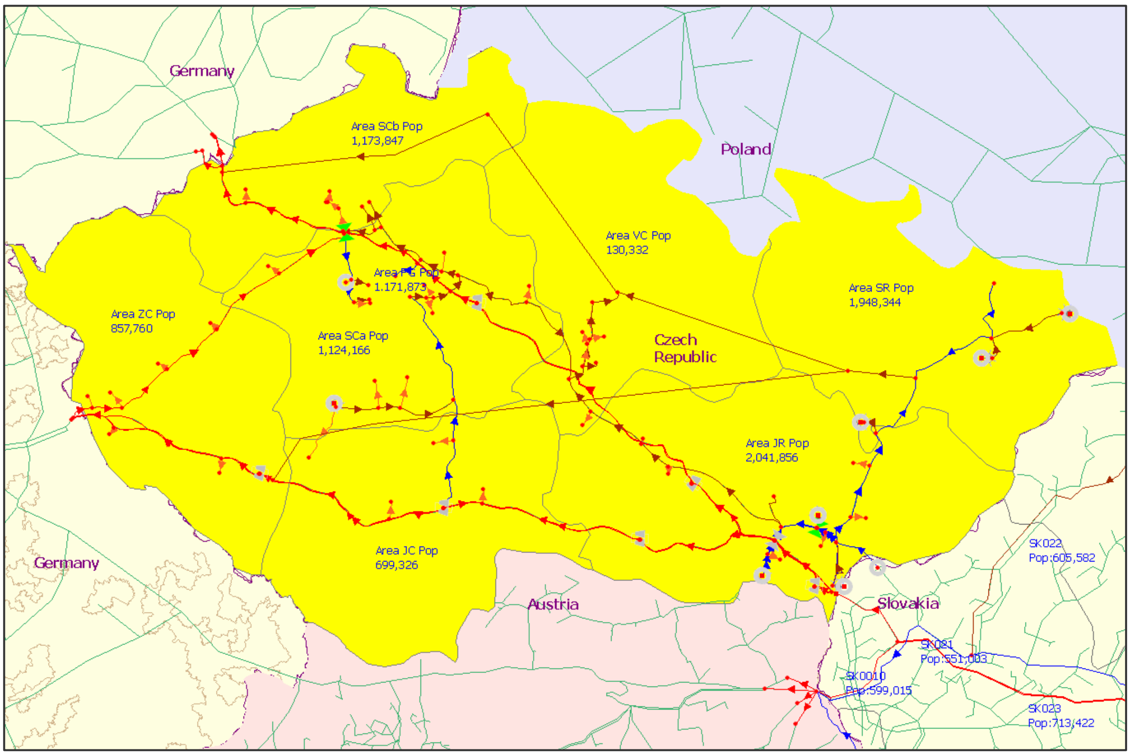


Figure 13: Trans-National & high pressure transmission pipelines in the Czech Republic

Figures 14 and 15 show, at increasing magnification, further detail of the modelled facilities. In Figure 14 the automated labelling of facilities and selected performance parameters may be seen. At this resolution multiple pipelines are just visible.

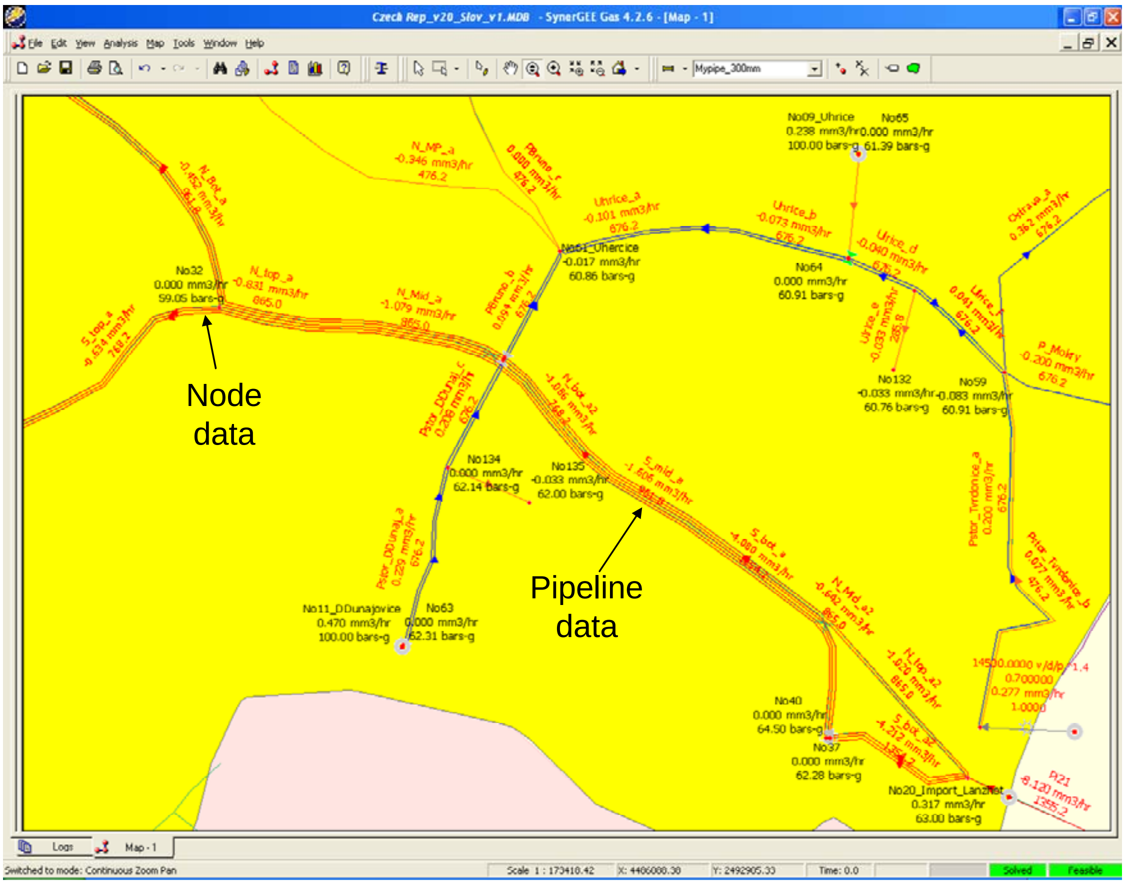


Figure 14: Detail showing annotation of pipelines and nodes

In Figure 15 several pipelines can be seen to occupy the same Right Of Way (ROW) but much higher resolution is also possible when required (see for example, Figure 11). A total in excess of 1000 facilities with a total pipeline length of 15,148km and 974 active nodes are included in the final model.

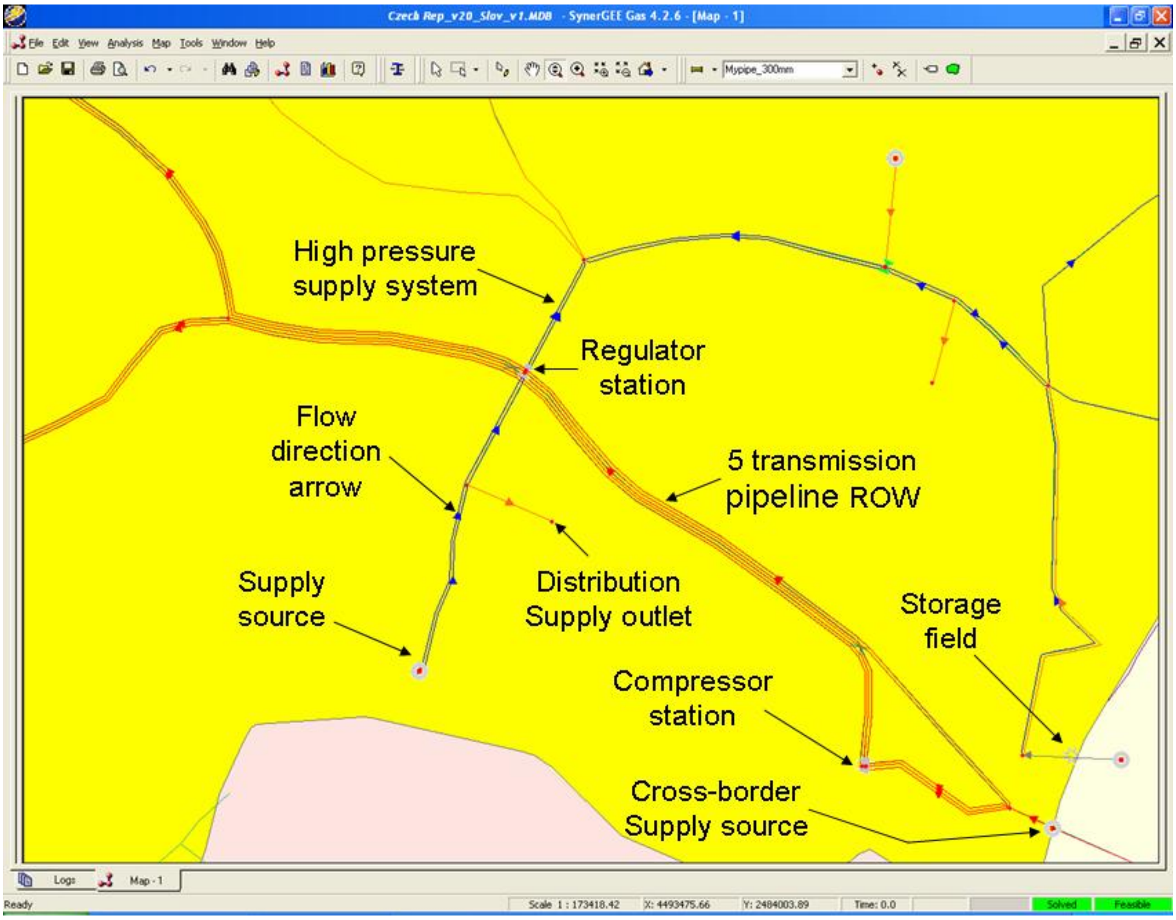


Figure 15: Key components in the model

12.0 Facility geographical location using Google Earth

The shape files for geographically locating pipelines used in the simulation model were converted into kml files suitable for loading into Google Earth. The advantage of displaying the pipeline routes in Google Earth is that other geographical features are often easily identified, providing the imagery of the area has sufficient resolution. Examples of large pipeline features such as a compressor station site, a metering station and a pipeline bridge river crossing are shown in Figures 16, 17 and 18 respectively. Although adequate for display purposes, however, the geo-referencing of the pipeline overlays, shown in green, are not particularly precise, as indicated in Figures 16 and 19, and further effort would be required to improve this situation.

Figure 16: Example of a compressor station site from Google Earth

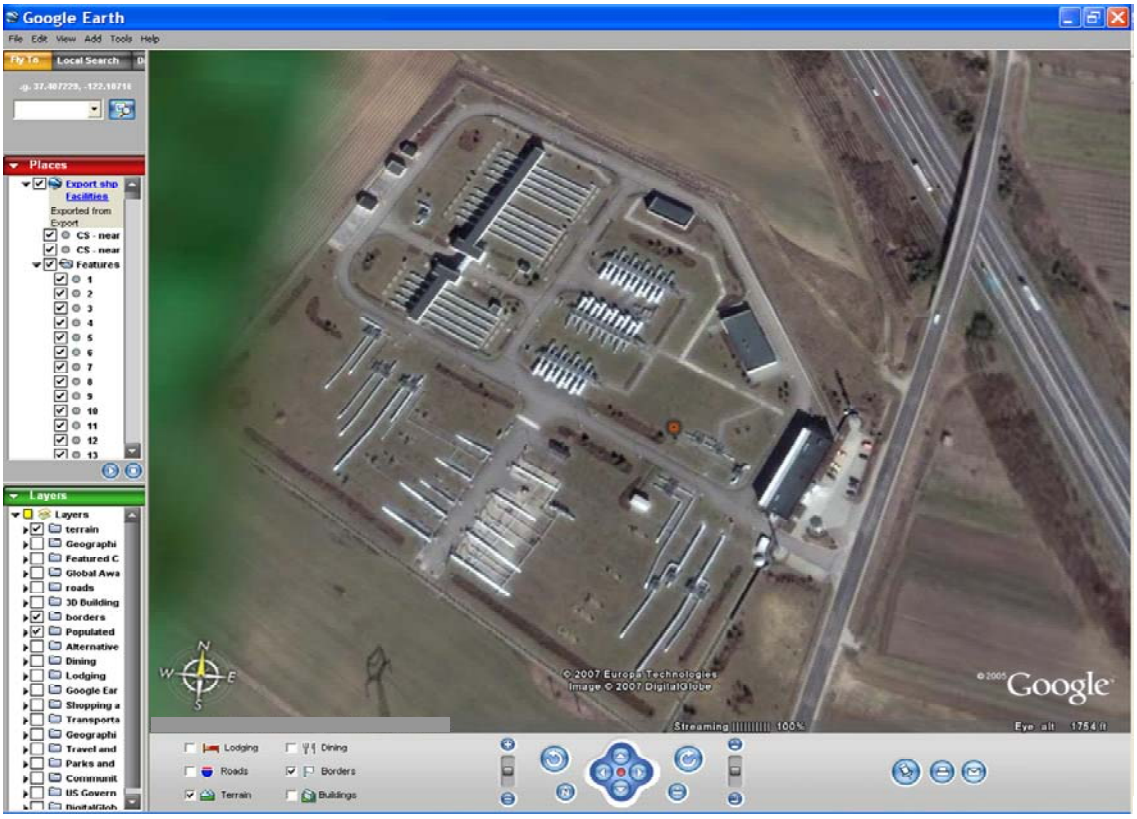


Figure 17: Example of a border crossing station from Google Earth

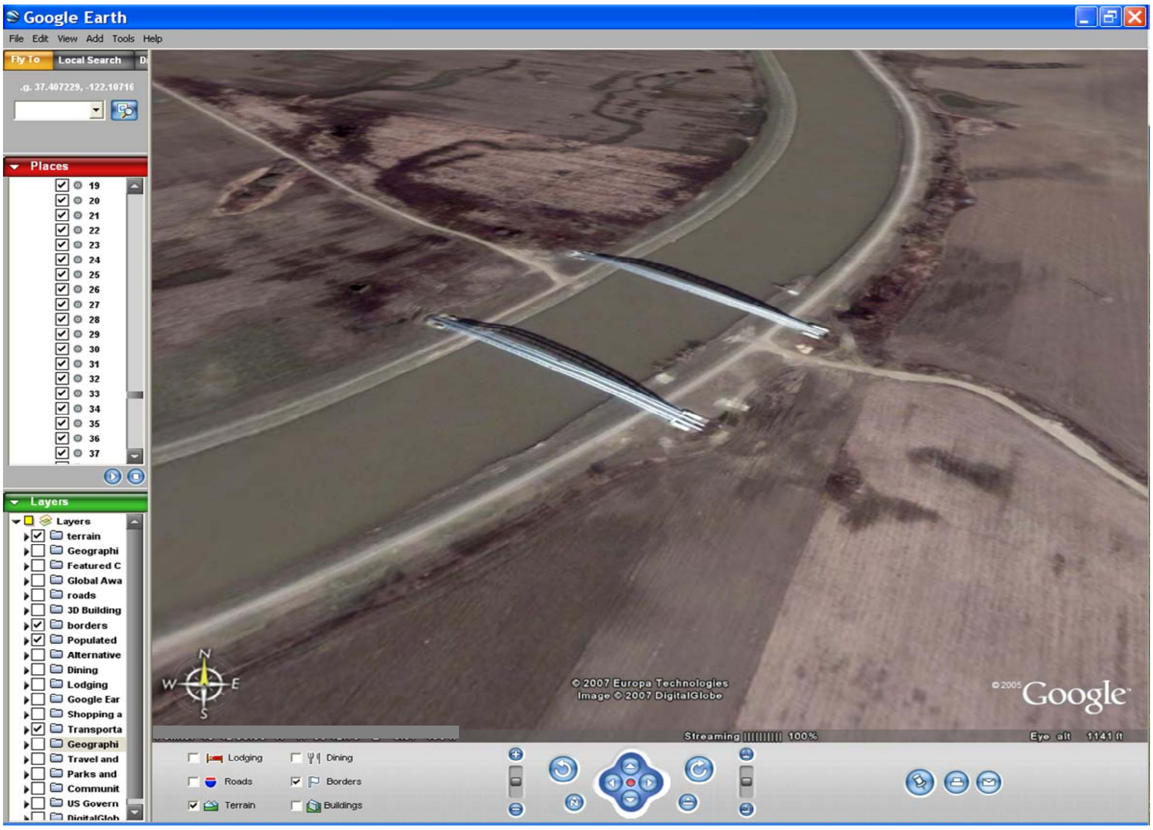


Figure 18: Bridge transmission pipeline crossing from Google Earth

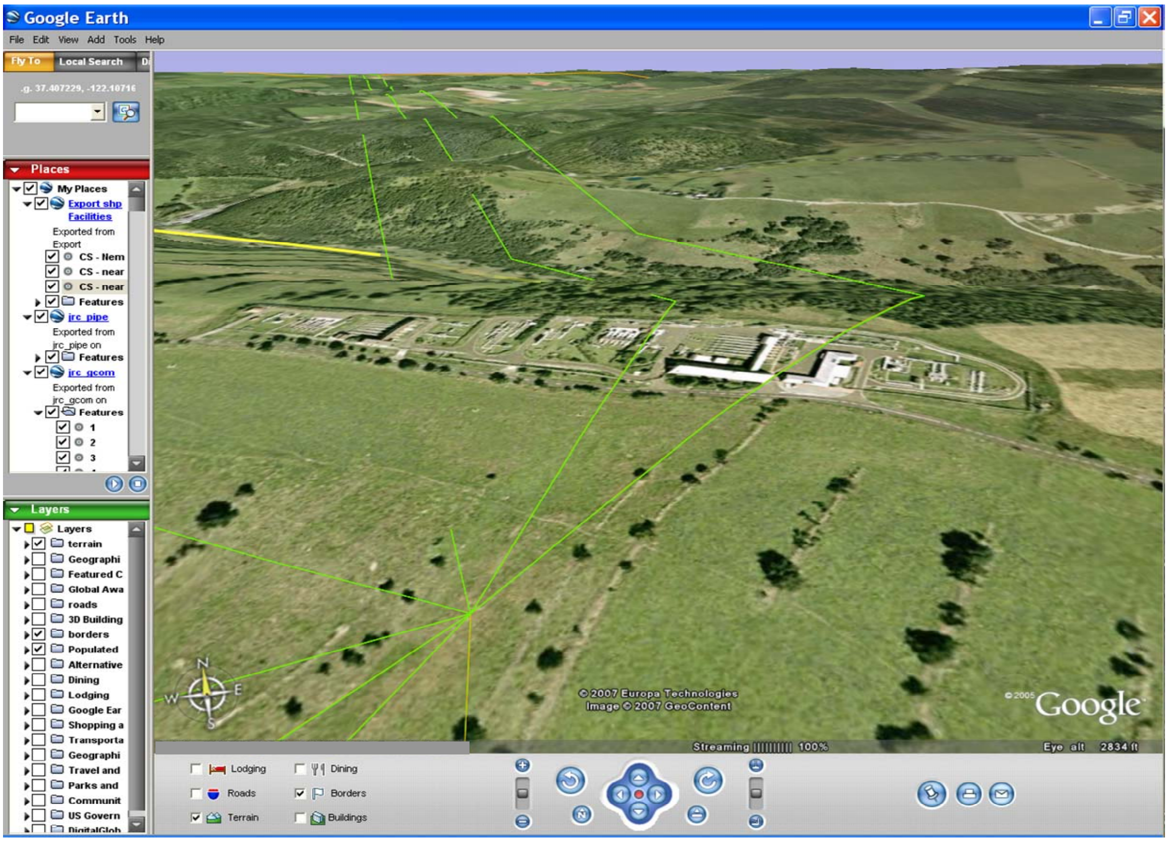


Figure 19: Geo-location of pipelines for compressor station compared with Google Earth

13.0 Model analysis and initial results

In Figure 20 the locations of the key border international input & output gas transmission pipelines are indicated by letters.

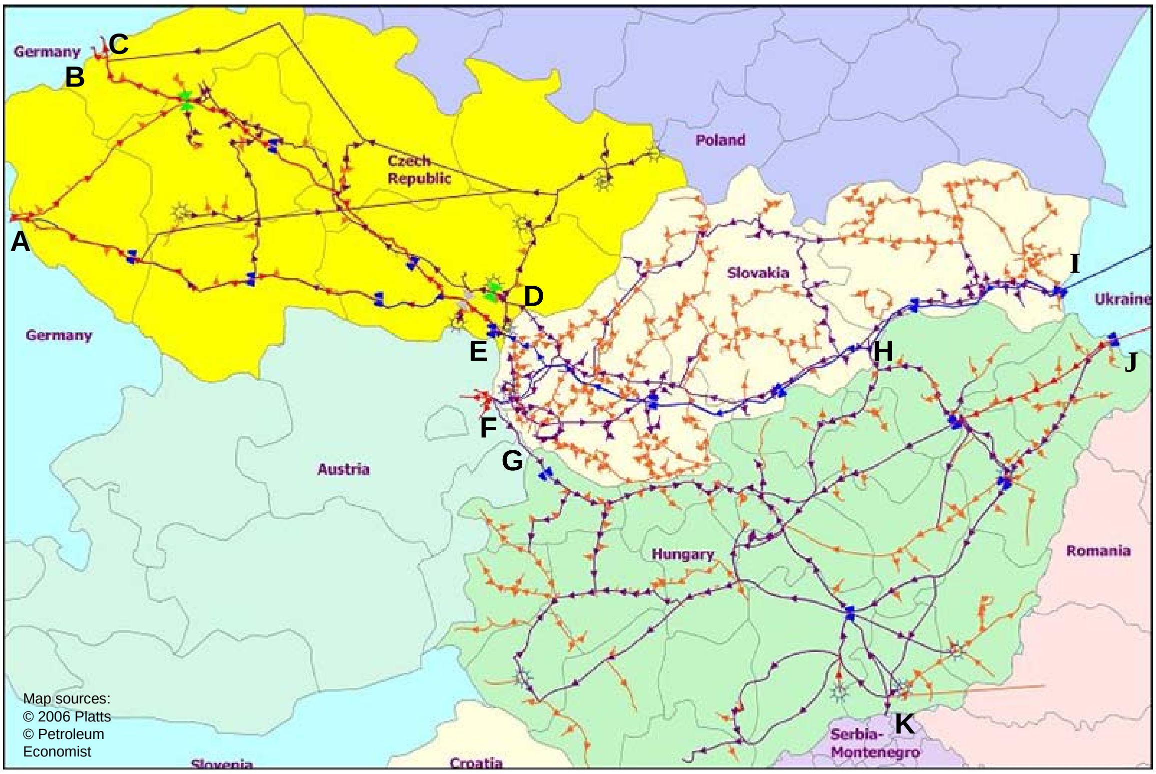


Figure 20: Locations of cross-border international transmission pipelines

The flow rates at these points, in mm^3/hr, provided by GTE in 2005[6] for the countries used in the model are shown in Table 7. For the entire model to be analyzed it is only necessary to assign flow rates to each individual pipeline input or output from the system. At least one pressure must be included if the entire network is interconnected, but additional pressures however must also be specified for the compressor stations themselves. All the remaining pressures, including those determined from the compressor characteristics, and flow rates are then calculated throughout the system.

Following the addition of each component item to the model during development, an analysis run was performed to ensure that a solution could always be obtained, even though such a solution may not be a practically realistic scenario. It appears from this exercise that the compressor stations are the most critical during the design phase and since there are 15 such stations this is cause for concern; a small change in parameters may result in many error messages.

A related issue identified is that on occasion the software reports a failure to converge but does not provide any error messages identifying the cause of the problem. It has been suggested by the support services of the software supplier that this failure may be a result of the choice of flow equation used in the model. They would recommend the use of a flow equation incorporating variable friction factors that result in increased pressure drops at higher flows. Alternative equations will therefore be explored in future work.

With the current model a system balance has been achieved, as indicated in the final column of Table 7. To simplify the display of what are currently considered to be the key parameters, the schematic diagram in Figure 21 has been constructed in Excel to show the arrangement of

Table 7: Flow rates and pressures assigned to cross-border points shown in Figure 21

Pre-set maximum flow rates from GTE border crossings - Dec. 2005

Maximum flow rates from GTE border crossing - Dec.2005

***Abovce = Not detailed in GTE list**

Country	Location		Border crossing		Location	Flow (mm^3/hr)		Pressure (Bar)		Balance of flow rates by country (mm^3/hr)												
	Map	Node	From	To	name	GTE Preset or Max.	Calc.	Preset	Calc.	Import		Production		Storage		Peak consumption		Export		Comp Fuel	Balance	
										Model	Max.	Model	Max.	Model	Max.	Model	Max.	Model	Max.		Model	Max.
Czech Republic	A	NGb01	Czech Republic	Germany	Waidhaus	**3.97**	-	-	58.10	7.992	6.7	0.014	0.014	1.734	1.771	2.689	2.687	7.00	7.00	0.050	0.001	-1.252
	B	NGa05			Obernhau	**1.20**	-	-	51.6													
	C	NGa03			Sayda	**1.83**	-	-	51.69													
	D	NSe62	Slovakia	Czech Republic	Mokry	0.20	0.216	-	58.66													
	E	NSe61			Lanzhot	**6.50**	7.776	-	58.68													
Slovakia	F	NA01	Slovakia	Austria	Baumgarten	**6.00**	6.065	-	56.85	15.160	12.75	0.011	0.011	0.994	1.000	1.779	1.781	14.22	12.70	0.163	-0.001	-0.883
	H	NHr21		Hungary	Abovce*	0.00	0.167		76													
	I	NUa03	Ukraine	Slovakia	Velke Kapusany	**12.75**	15.16	**71.96**	135													
	D	NSe62	Slovakia	Czech Republic	Mokry	0.20	0.216	-	58.66													
	E	NSe61			Lanzhot	**6.50**	7.776	-	58.68													
Hungary	J	NUb02	Ukraine	Hungary	Beregdaroc	**1.72**	2.088	**61.42**	110	2.82	2.22	0.339	0.339	1.837	1.980	4.430	4.430	0.54	0.54	0.028	-0.001	-0.459
	G	NHg23	Austria	Hungary	Mosonmagyarova	**0.50**	0.565	-	64													
	K	NHc01	Hungary	Serbia	Kiskundorozsma	**0.54**	0.54	-	49.41													
	H	NHr21	Hungary	Slovakia	Abovce*	0.00	0.167	-	76													
Totals										25.972	21.67	0.364	0.364	4.565	4.751	8.898	8.898	21.764	20.24	0.24	-0.001	-2.593

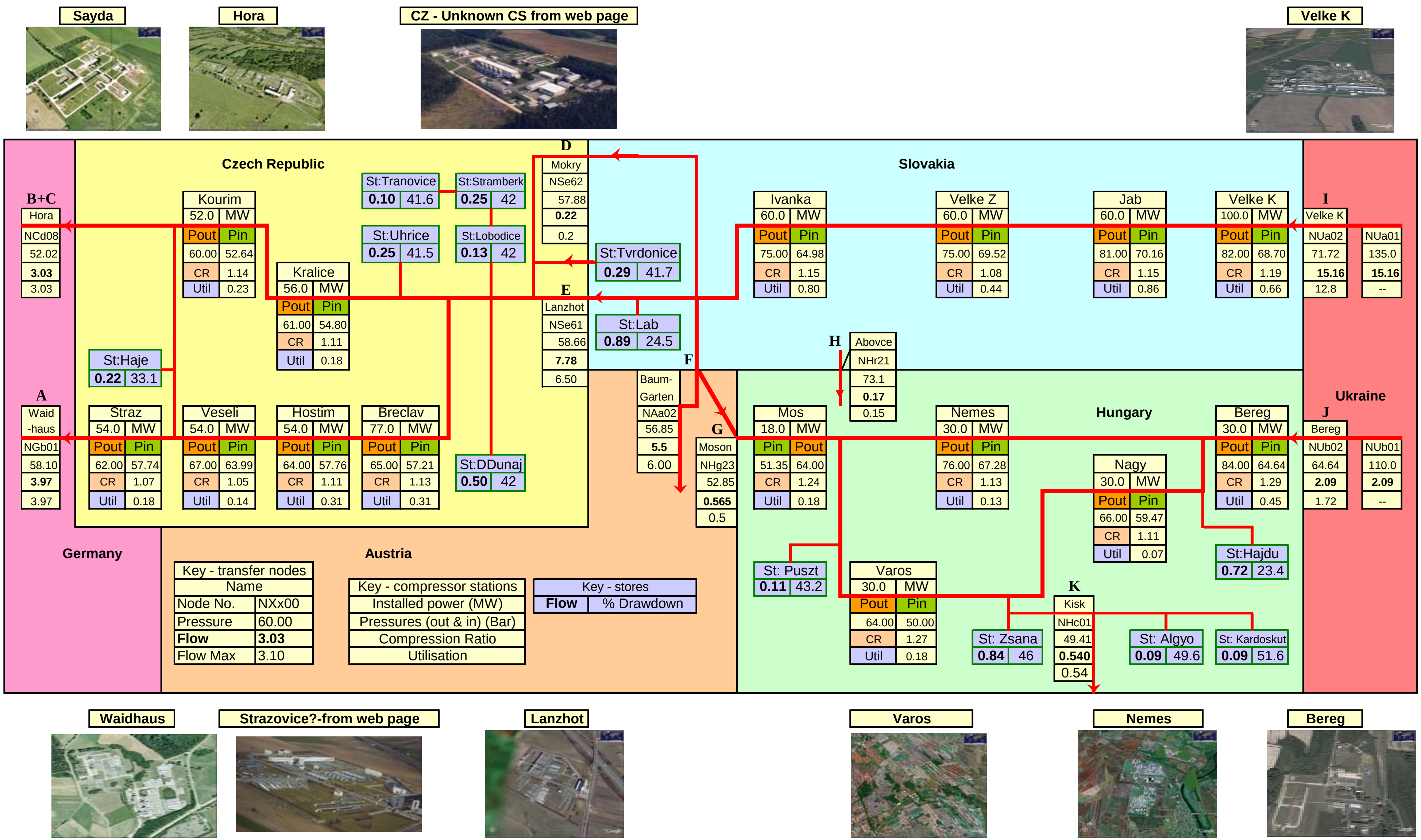


Figure 21: Example model input/output pressures at compressor stations & country borders

stations with key input/output pressures. Data can be directly exported from the pipeline model into the underlying spreadsheets of the Excel diagram. In addition to a fully populated map display, SynerGee offers a range of standard report formats to display results, an example being provided in Appendix VII.

14.0 Application to European Critical Infrastructure

Since there is such a vast amount of result data available it is necessary to decide on which are the critical features in the model and which are the key parameters that may represent changes to these features. This process is expected to require considerable analysis of a range of scenarios but in the first instance a simple set of criteria have been defined as follows:-

I. Cross-border pipelines.
   a. Reduce supply flow rates individually from the Ukraine to Slovakia and to Hungary and examine consequences to supplies to Czech Republic, Germany and Austria.
   b. Remove selected complete pipelines from the border supplies and examine consequences as in (a).

II. Compressor stations
   a. Examine number of stations and compressor units required to supply a range of demand flow options

III. Storage fields
   a. Examine the effect of removal of storage field supplies.

A related economic model predicting the consequences of reductions in supplies to effected regions is under separate development. As a consequence it is becoming apparent that a re-arrangement of system parameters that would provide more appropriate output from the pipeline model into the economic model is required. To achieve this, the currently determined maximum regional supplies should be re-configured from demand flow rates to limiting boundary conditions governed by set pressures and the software allowed to compute actual loads. This would be a reasonable approach since such off-takes would normally be controlled by pressure regulator stations. In this way reduced loads can be made available to the economic model. An issue to resolve is what would be acceptable demand load pressures.

15.0 Presentation of model and initial results to pipeline operators

Representatives of the major pipeline operators that operate in the modelled three countries were invited to attend a workshop held at the JRC, Ispra, on 7th September 2007[7]. Representatives from MOL of Hungary, SSP-Preprava of the Slovak Republic and RWE Transgas Net of the Czech Republic attended, together with additional representation from Geoplin Plinovodi of Slovenia and a representative from GIE, the Gas Pipeline Infrastructure group for Europe. The representatives were supportive of the general approach and were then invited to take away and complete a more detailed questionnaire. This 21 page questionnaire (provided in Appendix IX) requested opinions and additional data on all of the assumptions made in the model described in this report.

To date only one detailed response and one partial response have been received and analysis of these results is encouraging in that many assumptions are considered acceptable. However, one major change that must be addressed in future work is the incorrect assumption for the sizes of the compressor stations in Slovakia. Originally these were selected to be similar to those of the Czech Republic, where details were already known. However, it is now apparent that the power ratings of the Slovakia stations are up to three times larger, the largest being 290MW, whilst the line pressures are lower than expected. Additionally, the Ukraine supply pressure is considerably lower than anticipated at 43 to 54 bar compared with 71 Bar used in the model, whilst the Slovakia maximum pressures supplied by the compressor stations are limited to 73.5 Bar compared with the more typically calculated values used in the model of 75 to 82 Bar.

These alterations to the model are expected to reduce the current instability of the model to imposed changes to the infrastructure that are required in order to undertake the analysis of criticality of the system.

At an annual group forum "Team 2007", comprising specific users of the software in September 2007[8], where a presentation on this application of the software was given, it was revealed that a similar approach was also being applied by another organization to several Western European countries pipeline networks and that the approaches adopted were similar. The possibility of linking the models was discussed but with no decisions reached.

16.0 Conclusions

A first model of an integrated gas pipeline network has been built that represents the major gas transmission pipelines in three adjacent countries on a key pipeline route from Russia to the centre of Europe. There was general approval of the principles adopted and the underlying concepts of the model during a one-day workshop demonstration to the country pipeline operatives. The stability of the model is however currently poor, as demonstrated when parameters are altered too far from the operating regimes set in the model and further work is required to improve this aspect. The application and usefulness of the model for evaluation of proposed cross-cutting criteria in support of the EC Directive on European Critical Infrastructure can now be examined. The benefits of this exercise will be fully realized when the model is linked to related economic models, assessments of number of casualties, public effects and other consequences of system failures.

17.0 References

1. Development of a technical strategy for assessing the longer-term security & reliability of gas supply routes to Europe. Russell D Pride & Stanley D Morris. EUR 22248 EN. 2006

2. GENERCIS Note: A tool to aid improved understanding of the Gas Energy Network for Europe, Russia and the Commonwealth of Independent States. Russell D Pride & Stanley D Morris. Technical Note IPSC/TN/2006/050. 2006.

3. Development of a tool to aid improved understanding of the Gas Energy Network for Europe, Russia and the Commonwealth of Independent States. "GENERCIS". Russell D Pride & Stanley D Morris. (Not yet published).

4. International Energy Agency - IEA. Flexibility in natural gas supply and demand. 2002.

5. ERGEG Report: Monitoring the implementation of the guidelines for good TPA practice for storage system operators (GCPSSO). 2005.

6. GIE Gas Infrastructure Europe web site. (www.gte2.be)

7. European Critical Gas Infrastructure Modelling. A one-day workshop at the JRC. (Ispra, Italy) 7th September 2007. JRC40220.

8. EU Gas Infrastructure Modelling – the Beginnings of a Detailed Flow Model. Team 2007 Users Forum. 15-17th October 2007, Cambridge, UK. JRC42221.

APPENDIX I : Software selection

Table A1.1:
Companies identified with possible software products

Organization	Country	Product
Advantica Ltd	UK / USA	SynerGEE
Deloitte-Touche	UK	Ignite
Gasunie	Belgium	Pimslider
Atmos International Ltd	USA/UK	GSIM
Baseline Technologies	USA	PICS
Bradley B. Bean, PE	USA	Gasworks
Energy Solutions Int.	Belgium	Pipeline- studio
Gregg Engineering	USA	WinFlow/Winran
KORF	Canada	Korf
Liwacom	Germany/Czech Rep.	SIMONE
PSI Oil & Gas	Germany	PSIG

Table A1.2: Software requirements - assessed on a ranked basis

Issue	Detailed requirement
Module costs	Final purchase price of all software modules
	Subsequent annual license maintenance cost of software modules
	Costs of training
Functionality	Calculation of steady state gas flows
Language	The language of the software should be English
Maturity	To be demonstrated. Considered mature either as 1 year in use internally or externally
Availability & delivery	Immediate availability required with acceptable method of delivery
Environment	Software runs on PC in windows environment
Self check & help	Software capable of identifying inconsistencies in entry data in a helpful manner
	The software should be provided with extensive help files
	Data field & function labeling should be simply identified in a user friendly format
	An instruction “undo” facility should be available
License agreement	The product should be available for a limited evaluation period (eg. 1 month)
	License agreement to allow the JRC to modify/expand system for own internal use
	The license must allow results arising from the JRC to be published
	Inform JRC of updates & agree on cost to be provided in initial purchase agreement
Demonstration & sales literature	The supplier to provide a free demonstration at a place of mutual agreement
	Supply of technical or sales literature available on the software
Training & Support	Training facilities provided for using the software at suppliers or JRC offices
	Help desk contactable by phone or e-mail with a functional response time of 24 hours or better
Pipeline base mapping & vector layers	Input of base geographical maps. i) Scanned in from file or ii) Raster
	Vector layers already available & incorporated in currently used GIS operating environment
	iii) Vector - point; line; polygon
	Capability of linking different maps at boundaries (GIS co-ordinates)
	Capability to zoom on base maps and infrastructures
Pipeline routing	Input of major pipeline routes through use of mapping co-ordinates
	Input of pipeline routes from pipeline operators electronic data bases if/when available
	Input via laying pipeline routes directly onto a displayed map
	Input of pipelines by drawing, dragging & dropping or similar arrangement onto a base map
	Input of Right of Way (ROW) (distance from pipe centerline)
Pipeline properties	Input of identification labels for pipelines – eg. (name, country, etc)
	Input of key pipeline property parameters linked to specific pipeline sections (database)
	xyz pipeline co-ordinates – ie. including depth of cover
	Input of pipeline infrastructures such as compressor stations, heaters, regulators, etc.
	Capability of adding image or text files to provide support information to pipeline nodes
	& displaying these via a point-and-click map interface.
	Capability of providing different icons to represent pipeline features and attributes
Gas qualities/quantities	Input of major energy source and sink quantities linked to location examples:-
	a) volume cm/hr; (eg. by day, month, season) b) energy content cv
	Input of possible gas loss factors linked to pipe section
	Input of gas temperature at entry. Input of surrounding terrain ambient temperature
	Future requirement for entering gas composition
	Capability of inserting financial data into the model eg. Tariff rates
Software calculations	Single phase flow modeling for pipes/fittings of various dimensions & materials
	Capability to simulate easily, a change of state of valves – eg. open/closed
	Calculation of gas temperature
	Calculation of immediately surrounding terrain temperature
	Reduction in pipe design operating pressure resulting from stress analysis
Database environment & linkage to future data	Inputs for i) Cathodic protection survey data. ii) Pigging data. iii) Remote surveillance data
	Support of standard data formats eg. APDM
	Interfaces to i) Arc GIS environment. ii) Excel spread sheets. iii) MS Access
Data manipulation, display & outputs	Capable of displaying multi-parameter database enquires
	Tabular results of data constructed by user from selection of input & calculated values
	From given input gas flows display input/output flows & pressures at multiple locations
	From given output flows display required input flows & pressures at multiple locations
	Provide options of gas inputs at set locations to meet required outputs at other locations
	Graphical results – provide all result combinations as optional graphical displays
	Map displays - provide key result combinations as optional graphical displays
Risk Analysis	Multi-format input & output files

APPENDIX II : Model settings used in simulations

Table A2.1
Universal modelling parameters used in SynerGee

Feature	Item	Value	Units
Pipeline	Efficiency	1.0	-
	Friction factor	0.015	-
	Roughness	0.0635	mm
Gas properties	Flow temperature	15.5	^oC
	Heat content	37.26	Mj/m^3
	Specific gravity	0.6	-
	CO2 content	0.5	-
	Viscosity	0.01197006	cP
Ambient conditions	Temperature	15.5	^oC
	Pressure	1.0156	Bar
	Elevation	0.0	m
Mapping	Co-ordinate system		GCS_WGS_1984

Note: The value of these parameters may be changed.

Table A2.2
Common parameters used in compressor stations

Parameter		Value	Unit		Value	Unit		Value	Unit
Yard loss – suction		0.3	Bar	-	-	-	-	-	-
Yard loss - discharge		0.3	Bar	-	-	-	-	-	-
Fuel versus minimum power level		350	kW	-	-	-	-	-	-
Fuel coefficients	C_0	1295.67	$m^3/kW\text{-}hr/kW$	C_1	0.017043	$m^3/kW\text{-}hr$	C_2	0.000072	$m^3/kW\text{-}hr\text{-}kW$
Compressor k values	K_1	121979.8	-	K_2	121663.8	-	K_3	0.231	-

Table A2.3
Some shapefile names with descriptions

File name	Source	Function	Size	Shape
ehold	IDAS - DMA	Europe country borders –(includes electrical regions)		
ester		Europe with regions & borders		
gstor		gas stores & LNG	40	
gcom		gas compressors	30	
gsint		gas interchanges between companies	42	
gfac		gas facilities/platforms/etc	36	x
pipe		gas pipelines	1	
garea		gas regions/reserves		
lngim		LNG import terminal		
plant		Elec/gas eg.supply/sink eg.windmill/factory	34	
port		Any	26	
subs		Elec. sub stations-but can be specific to gas	31	

Table A2.4
Base mapping layers

File type	Layer name & optional selection box ☑		Line/point type	Fill type	Size Width	Line/symbol colour	Fill colour	Selectable	Comments
SynerGee	☑	Nodes	-	-	-	-	-	☑	
	☑	Supply nodes	-	-	-	-	-	☑	
	☐	Selected nodes	Diamond	-	10	Turquoise	-		
	☑	Facilities	-	-	-	-	-	☑	
	☐	Selected facilities	Thin line	-	2	Turquoise	-		
	☐	Polygons							May be used for a range of applications
DMA	☑	jrc_pipe	Thin line	-	1	Blue	-	☑	
Open source shape files from CDC[1] & VDS[2]	☐	ez.shp (Czech Republic)	Select thick or thin lines to show boundaries	solid	0.4	Yellow	Yellow		Optional colour coding of countries – include country, regional administrative boundaries & populations. Additional countries may be included.
	☐	hungary.shp (Hungary)		solid	0.4	Green	Green		
	☐	austria.shp (Austria)		solid	0.4	Rose	Rose		
	☐	hr.shp (Croatia)		solid	0.4	Grey	Lavender		
	☐	Lo.shp (Slovakia)		solid	0.4	Pale yellow	Pale yellow		
	☐	Pl.shp (Poland)		solid	0.4	Pale blue	Pale blue		
DMA shape files	☑	jrc_ehold	None	no fill	0.4	Violet	Light yellow		
	☑	jrc_gcom	■	-	-	-	-		
	☑	jrc_gstor	✹	-	-	-	-		
	☐	jrc_plant	◆	-	-	-	-		
Open source	☑	cities.shp	-	solid	0.4	Tan	Light yellow	☑	
SynerGee	☑	Polygons	-	-	-	-	-	☑	See Editing polygons & Symbology settings
Open source shape files	☑	world_adm0.shp		solid	0.4	Violet	Light yellow	☑	Move below europe for improved border resolutions
	☑	europe,shp	-	solid	0.4	Grey	Lavender	☑	

General information for setting up basic SynerGee mapping background. Layers may be rearranged to display selected features in the foreground. Features such as labels and annotation may also be individually switched on and off.

1. Free download data: CDC Shape files. Population by regions. 1994 population data. http://www.vdstech.com/map_data.htm
2. Free download data: VDS Shape files. Population by regions. 1994 population data. http://www.cdc.gov/epiinfo/europe.htm

APPENDIX III : Pipeline internal diameter selection

Pipelines are usually referenced by their external diameter which in many instances is quoted in inches. However, it is the internal diameter that determines the flow properties. The internal diameter is determined by the wall thickness that in turn is selected to meet the required pressure regime the pipe is designed to operate within. The age of existing pipelines may range up to 50 years old and it would be very difficult to establish the design criteria without approaching the individual pipeline operators. Currently there are a range of preferred pipeline sizes as indicated in Table A3.1 below (brown highlighted are additional estimates), dependent on material grade, the yellow highlighted diameters being used in this model.

Table A3.1

Current preferred industry pipe sizes.

Outside diameter		wall thickness	Internal diameter	Pipe grade	SMYS (S)	Max. pressure
in	mm	mm	mm	X -	Bar	Bar
6.6	168.3	5.6	157.1	42.0	2,857.1	114.1
	168.3	7.1	154.1	42.0	2,857.1	144.6
	168.3	11.9	144.5	42.0	2,857.1	242.4
8.6	219.1	6.4	206.3	42.0	2,857.1	100.1
	219.1	8.2	202.7	42.0	2,857.1	128.3
	219.1	12.7	193.7	42.0	2,857.1	198.7
10.8	273.1	6.4	260.3	52.0	3,537.4	99.5
	273.1	8.7	255.7	52.0	3,537.4	135.2
	273.1	12.7	247.7	52.0	3,537.4	197.4
12.8	323.9	7.1	309.7	52.0	3,537.4	93.0
	323.9	9.5	304.9	52.0	3,537.4	124.5
	323.9	12.7	298.5	52.0	3,537.4	166.4
16.0	406.0	8.7	388.6	52.0	3,537.4	91.0
	406.0	10.3	385.4	52.0	3,537.4	107.7
	406.0	14.3	377.4	52.0	3,537.4	149.5
18.0	457.0	9.5	438.0	52.0	3,537.4	88.2
	457.0	11.9	433.2	52.0	3,537.4	110.5
	457.0	15.9	425.2	60.0	4,081.6	170.4
24.0	610.0	9.5	591.0	52.0	3,537.4	66.1
	610.0	14.3	581.4	52.0	3,537.4	99.5
	610.0	19.1	571.8	60.0	4,081.6	153.4
30.0	762.0	11.9	738.2	52.0	3,537.4	66.3
	762.0	15.9	730.2	60.0	4,081.6	102.2
	762.0	19.1	723.8	60.0	4,081.6	122.8
	762.0	22.2	717.6	60.0	4,081.6	142.7
36.0	914.0	12.7	888.6	60.0	4,081.6	68.1
	914.0	15.9	882.2	65.0	4,421.8	92.3
	914.0	19.1	875.8	60.0	4,081.6	102.4
	914.0	25.4	863.2	65.0	4,421.8	147.5
42.0	1067.0	14.3	1038.4	60.0	4,081.6	65.6
	1067.0	17.5	1032.0	65.0	4,421.8	87.0
	1067.0	19.1	1028.8	65.0	4,421.8	95.0
	1067.0	28.7	1009.6	65.0	4,421.8	142.7
48.0	1219.0	15.9	1187.2	65.0	4,421.8	69.2
	1219.0	19.1	1180.8	65.0	4,421.8	83.1
	1219.0	22.4	1174.2	65.0	4,421.8	97.5
	1219.0	25.4	1168.2	65.0	4,421.8	110.6
	1219.0	14.3	1190.4	80.0	5,442.2	76.6
	1219.0	15.9	1187.2	80.0	5,442.2	85.2
	1219.0	20.6	1177.8	80.0	5,442.2	110.4
	1219.0	22.9	1173.2	80.0	5,442.2	122.7
56.0	1423.0	22.9	1377.2	80.0	5,442.2	105.1
56.0	1423.0	25.0	1373.0	90.0	6,122.4	129.1

The SMYS (Specified Minimum Yield Strength) has been calculated from equation (i) below.

The maximum operating pressure can be determined in several different ways, some approaches using advanced risk analysis. However, for the current analysis, these approaches require far too much knowledge of the pipeline route and current operational status; hence a simple approach has been adopted. The maximum operating pressure has been determined from equation (i) using an American approach to de-rating factors.

$$P = \{2 \times t \times S \times (E \times F \times T)\} / D \quad \text{……………………. (i)}$$

Where:-

P = Pressure (Bar)
t = wall thickness (mm)
S = SMYS (Specified Minimum Yield Strength)
D = Diameter (mm)

And design de-rating factors are:-

E = Seam joint factor (taken as 1 for this analysis)
F = Class factor (conservatively taken as 0.6 from Table A3.2 below)
T = Temperature de-rating factor (taken as 1 for this analysis)

Table A3.2
Class factors for de-rating pipelines

Class	Factor	Location or distance either side of pipe centre line	Number of dwellings per unit length		unit area		Land area per dwelling	
			No./mile	No./km	No./mile^2	No./km^2	yds^2	m^2
1	0.7	Offshore & rural	<10	16	40	15	77,440	64,750
2	0.6	Within 220yds (201m)	<46	74	184	71	16,835	14,076
3	0.5	Within 220yds (201m)	>46	74	184	71	16,835	14,076
4	0.4	Towns & cities	Urban	-	-	-	-	-

In order to simplify the SynerGee analysis and work with a standard set of metric outside diameter pipelines a selection of pipe sizes has been chosen from the list in Table A3.1 (highlighted in yellow) to provide maximum operating pressures in the order of 100 Bar. These could be significantly de-rated further if corrosion or other defects require this, whilst still maintaining acceptable operating pressures (see Table A3.2). In the case of the 36inch pipe a mean value of wall thickness was chosen, whilst for the 56inch diameter pipeline a wall thickness has been estimated. Where available data specifies diameter in integer inches the nearest integer metric diameter has been selected.

Table A3.3
Final preferred pipe dimensions used in simulation

External diameter		wall thickness		Internal diameter	Pipe grade	SMYS	Max. pressure
in	mm	mm	As % of OD	mm	X -	Bar	Bar
5.9	150.0	5.6	3.7	138.8	42.0	2,857.1	128.0
8.7	220.0	6.4	2.9	207.2	42.0	2,857.1	99.7
11.8	300.0	7.1	2.4	285.8	60.0	4,081.6	115.9
15.7	400.0	8.7	2.2	382.6	60.0	4,081.6	106.5
19.7	500.0	11.9	2.4	476.2	60.0	4,081.6	116.6
23.6	600.0	14.3	2.4	571.4	60.0	4,081.6	116.7
27.6	700.0	11.9	1.7	676.2	60.0	4,081.6	83.3
31.5	800.0	15.9	2.0	768.2	60.0	4,081.6	97.3
35.4	900.0	17.5	1.9	865.0	65.0	4,421.8	103.2
39.4	1000.0	19.1	1.9	961.8	65.0	4,421.8	101.3
47.2	1200.0	22.4	1.9	1155.2	65.0	4,421.8	99.0
55.1	1400.0	22.9	1.6	1354.2	80.0	5,442.2	106.8

A sensitivity analysis of the effect of internal pipeline diameter on pressure drop shows that for a 10bar pressure drop over 200km, the effect of changing wall thickness on flow rate is as shown in Figure A3.1 for four different pipe diameters. This means that the selection of preferred wall thickness that is in fact incorrect could influence pipeline flow rates by several percent.

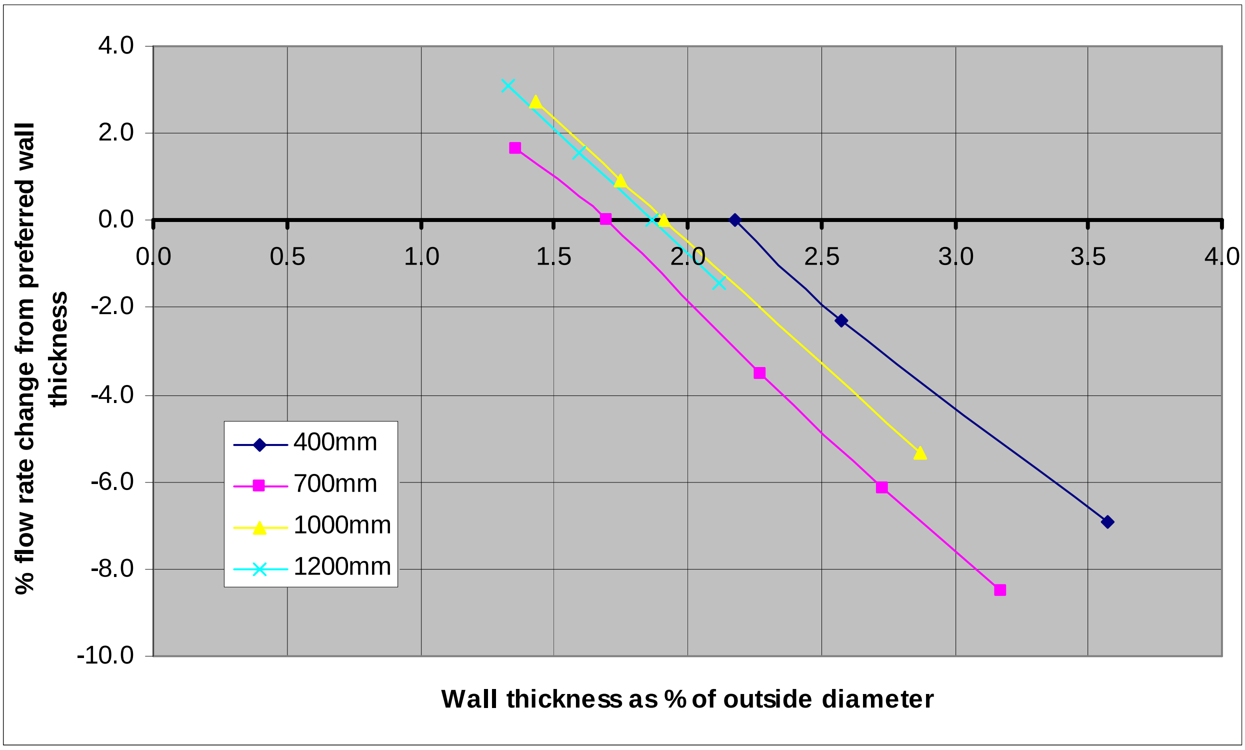


Figure A3.1: Effect on flow rate of pipeline wall thickness for various pipe diameters

Apart from the supply pressures for storage fields the maximum pressure in the current model does not exceed 84Bar so that there is scope for further de-rating of pipelines if required. Also at present no boundary maximum pressures have been set for individual pipeline sections (there are 1064) so it would be possible with further knowledge to apply limiting boundary operating conditions for all the pipes in the system.

APPENDIX IV : Compressor station assemblies

Table A4.1 Driver/compressor combinations

Kourim - Co9. Max. CR = 1.29

Path No.	Assembly name Co-xx	Driver Name Th-	Driver Rating MW	Compressor Name Ac-	Compressor Pmax Bar
1	6	5	6	7	83.5
2	19	17	6	16	83.5
3	6	5	6	7	83.5
4	25	24	10	23	83.5
5	28	27	6	26	83
6	31	30	6	29	83
7	19	17	6	16	83.5
8	6	5	6	7	83.5
9	-	-	-	-	-
10	-	-	-	-	-
11	-	-	-	-	-
TOT	-	-	52	-	-

Kralice - Co15. Max. CR = 1.3

Path No.	Assembly name Co-xx	Driver Name Th-	Driver Rating MW	Compressor Name Ac-	Compressor Pmax Bar
1	6	5	6	7	83.5
2	6	5	6	7	83.5
3	6	5	6	7	83.5
4	6	5	6	7	83.5
5	6	5	6	7	83.5
6	35	34	13	36	75.0
7	35	34	13	36	75.0
8	-	-	-	-	-
9	-	-	-	-	-
10	-	-	-	-	-
11	-	-	-	-	-
TOT	-	-	56	-	-

Ivanka - Co38. Max. CR = 1.3

Path No.	Assembly name Co-xx	Driver Name Th-	Driver Rating MW	Compressor Name Ac-	Compressor Pmax Bar
1	41	40	6	39	85
2	41	40	6	39	85
3	41	40	6	39	85
4	41	40	6	39	85
5	41	40	6	39	85
6	41	40	6	39	85
7	41	40	6	39	85
8	41	40	6	39	85
9	41	40	6	39	85
10	41	40	6	39	85
11	-	-	-	-	-
TOT	-	-	60	-	-

Velke-Z - Co42. Max. CR = 1.3

Path No.	Assembly name Co-xx	Driver Name Th-	Driver Rating MW	Compressor Name Ac-	Compressor Pmax Bar
1	45	44	10	43	85
2	45	44	10	43	85
3	45	44	10	43	85
4	45	44	10	43	85
5	45	44	10	43	85
6	45	44	10	43	85
7	-	-	-	-	-
8	-	-	-	-	-
9	-	-	-	-	-
10	-	-	-	-	-
11	-	-	-	-	-
TOT	-	-	60	-	-

Jab - Co20. Max. CR = 1.29

Path No.	Assembly name Co-xx	Driver Name Th-	Driver Rating MW	Compressor Name Ac-	Compressor Pmax Bar
1	6.00	5.00	6.00	7.00	83.50
2	6.00	5.00	6.00	7.00	83.50
3	6.00	5.00	6.00	7.00	83.50
4	6.00	5.00	6.00	7.00	83.50
5	6.00	5.00	6.00	7.00	83.50
6	25	24	10	23	83.5
7	25	24	10	23	83.5
8	25	24	10	23	83.5
9	-	-	-	-	-
10	-	-	-	-	-
11	-	-	-	-	-
TOT	-	-	60	-	-

Stazovice-Co12. Max.CR =1.22

Path No.	Assembly name Co-xx	Driver Name Th-	Driver Rating MW	Compressor Name Ac-	Compressor Pmax Bar
1	6	5	6	7	83.5
2	6	5	6	7	83.5
3	6	5	6	7	83.5
4	6	5	6	7	83.5
5	6	5	6	7	83.5
6	6	5	6	7	83.5
7	6	5	6	7	83.5
8	6	5	6	7	83.5
9	6	5	6	7	83.5
10	-	-	-	-	-
11	-	-	-	-	-
TOT	-	-	54	-	-

Veseli - Co11. Max. CR = 1.22

Path No.	Assembly name Co-xx	Driver Name Th-	Driver Rating MW	Compressor Name Ac-	Compressor Pmax Bar
1	6	5	6	7	83.5
2	6	5	6	7	83.5
3	6	5	6	7	83.5
4	6	5	6	7	83.5
5	6	5	6	7	83.5
6	6	5	6	7	83.5
7	6	5	6	7	83.5
8	6	5	6	7	83.5
9	6	5	6	7	83.5
10	-	-	-	-	-
11	-	-	-	-	-
TOT	-	-	54	-	-

Hostim - Co6. Max. CR = 1.22

Path No.	Assembly name Co-xx	Driver Name Th-	Driver Rating MW	Compressor Name Ac-	Compressor Pmax Bar
1	8	7	6	9	73.5
2	13	12	6	11	73.5
3	2	3	6	1	61.8
4	3	1	6	4	83.5
5	3	1	6	4	83.5
6	3	1	6	4	83.5
7	3	1	6	4	83.5
8	3	1	6	4	83.5
9	3	1	6	4	83.5
10	-	-	-	-	-
11	-	-	-	-	-
TOT	-	-	54	-	-

Breclav - Co13. Max. CR = 1.29

Path No.	Assembly name Co-xx	Driver Name Th-	Driver Rating MW	Compressor Name Ac-	Compressor Pmax Bar
1	6	5	6	7	83.5
2	6	5	6	7	83.5
3	6	5	6	7	83.5
4	6	5	6	7	83.5
5	6	5	6	7	83.5
6	6	5	6	7	83.5
7	6	5	6	7	83.5
8	6	5	6	7	83.5
9	6	5	6	7	83.5
10	4	2	23	5	73.5
11	-	-	-	-	-
TOT	-	-	77	-	-

Mos - Co21. Max. CR = 1.3

Path No.	Assembly name Co-xx	Driver Name Th-	Driver Rating MW	Compressor Name Ac-	Compressor Pmax Bar
1	6	5	6	7	83.5
2	6	5	6	7	83.5
3	6	5	6	7	83.5
4	-	-	-	-	-
5	-	-	-	-	-
6	-	-	-	-	-
7	-	-	-	-	-
8	-	-	-	-	-
9	-	-	-	-	-
10	-	-	-	-	-
11	-	-	-	-	-
TOT	-	-	18	-	-

Varos - Co16. Max. CR = 1.3

Path No.	Assembly name Co-xx	Driver Name Th-	Driver Rating MW	Compressor Name Ac-	Compressor Pmax Bar
1	20	18	10	17	83
2	20	18	10	17	83
3	20	18	10	17	83
4	-	-	-	-	-
5	-	-	-	-	-
6	-	-	-	-	-
7	-	-	-	-	-
8	-	-	-	-	-
9	-	-	-	-	-
10	-	-	-	-	-
11	-	-	-	-	-
TOT	-	-	30	-	-

Nemes-Co25.Max.CR = 1.29

Path No.	Assembly name Co-xx	Driver Name Th-	Driver Rating MW	Compressor Name Ac-	Compressor Pmax Bar
1	29	28	10	27	83
2	25	24	10	23	83.5
3	25	24	10	23	83.5
4	-	-	-	-	-
5	-	-	-	-	-
6	-	-	-	-	-
7	-	-	-	-	-
8	-	-	-	-	-
9	-	-	-	-	-
10	-	-	-	-	-
11	-	-	-	-	-
TOT	-	-	30	-	-

Nagy - Co19. Max. CR = 1.3

Path No.	Assembly name Co-xx	Driver Name Th-	Driver Rating MW	Compressor Name Ac-	Compressor Pmax Bar
1	23	20	10	25	85
2	23	20	10	25	85
3	23	20	10	25	85
4	-	-	-	-	-
5	-	-	-	-	-
6	-	-	-	-	-
7	-	-	-	-	-
8	-	-	-	-	-
9	-	-	-	-	-
10	-	-	-	-	-
11	-	-	-	-	-
TOT	-	-	30	-	-

Velke K - Co26. Max. CR = 1.3

Path No.	Assembly name Co-xx	Driver Name Th-	Driver Rating MW	Compressor Name Ac-	Compressor Pmax Bar
1	30	29	10	31	85
2	30	29	10	31	85
3	30	29	10	31	85
4	30	29	10	31	85
5	30	29	10	31	85
6	30	29	10	31	85
7	30	29	10	31	85
8	30	29	10	31	85
9	30	29	10	31	85
10	30	29	10	31	85
11	-	-	-	-	-
TOT	-	-	100	-	-

Bereg - Co18. Max. CR = 1.3

Path No.	Assembly name Co-xx	Driver Name Th-	Driver Rating MW	Compressor Name Ac-	Compressor Pmax Bar
1	21	19	10	24	85
2	21	19	10	24	85
3	21	19	10	24	85
4	-	-	-	-	-
5	-	-	-	-	-
6	-	-	-	-	-
7	-	-	-	-	-
8	-	-	-	-	-
9	-	-	-	-	-
10	-	-	-	-	-
11	-	-	-	-	-
TOT	-	-	30	-	-

Key:- Each colour band represents a set combination of driver/compressor

= various combinations

Deliberately left blank

APPENDIX V : Country pipeline mapping details

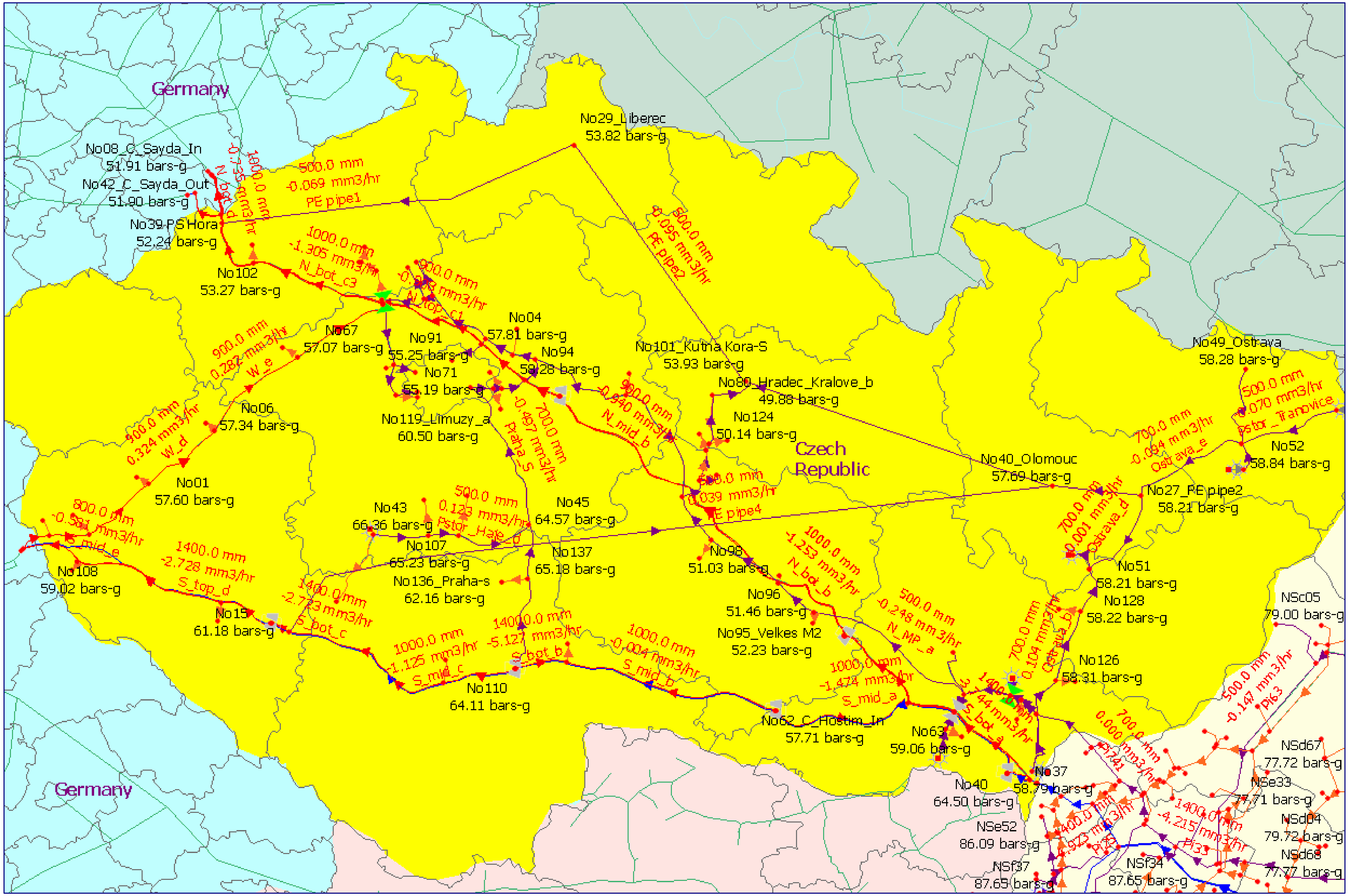


Figure A5.1 : Czech Republic pipeline model

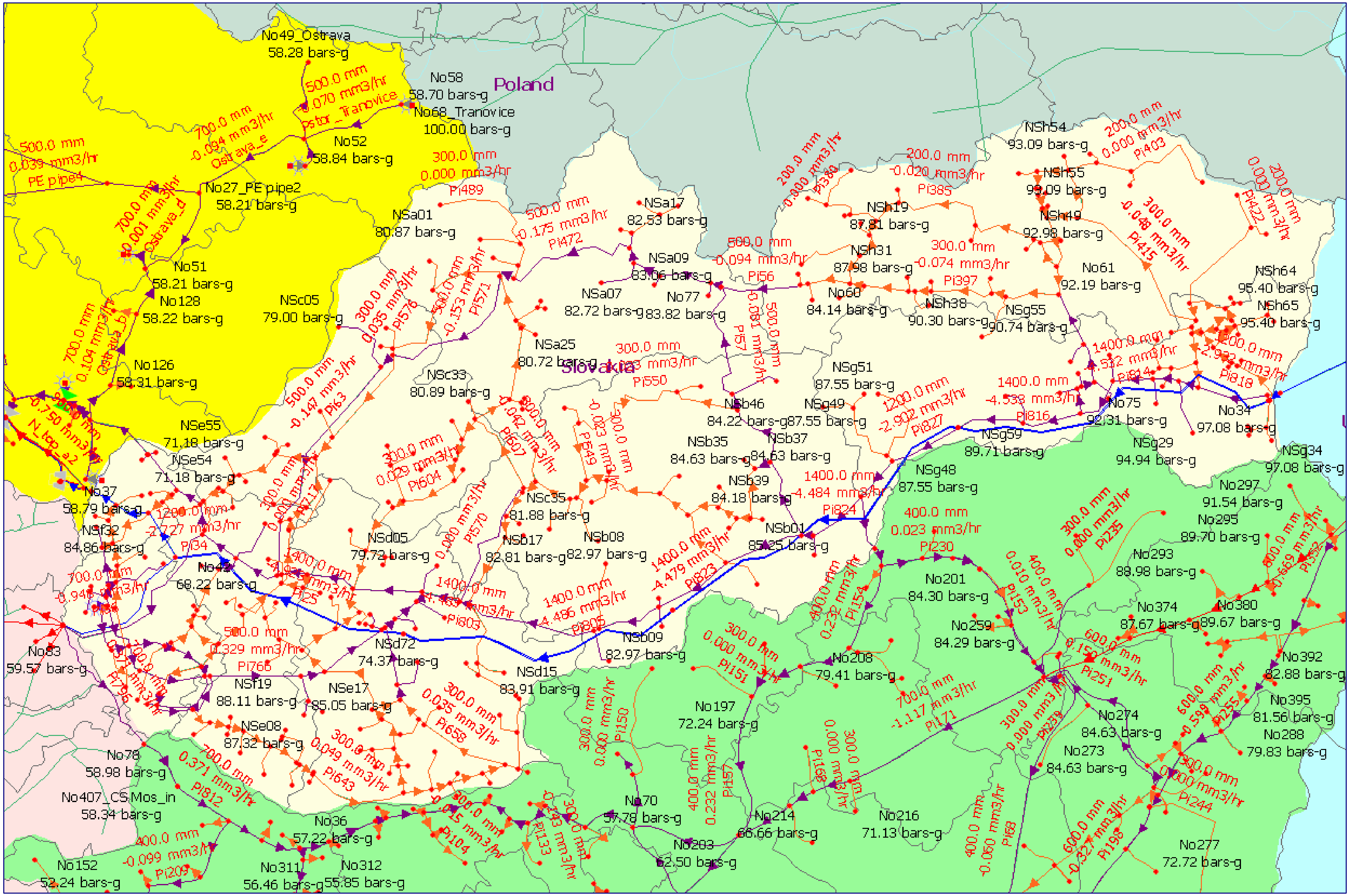


Figure A5 2 : Slovakia pipeline model

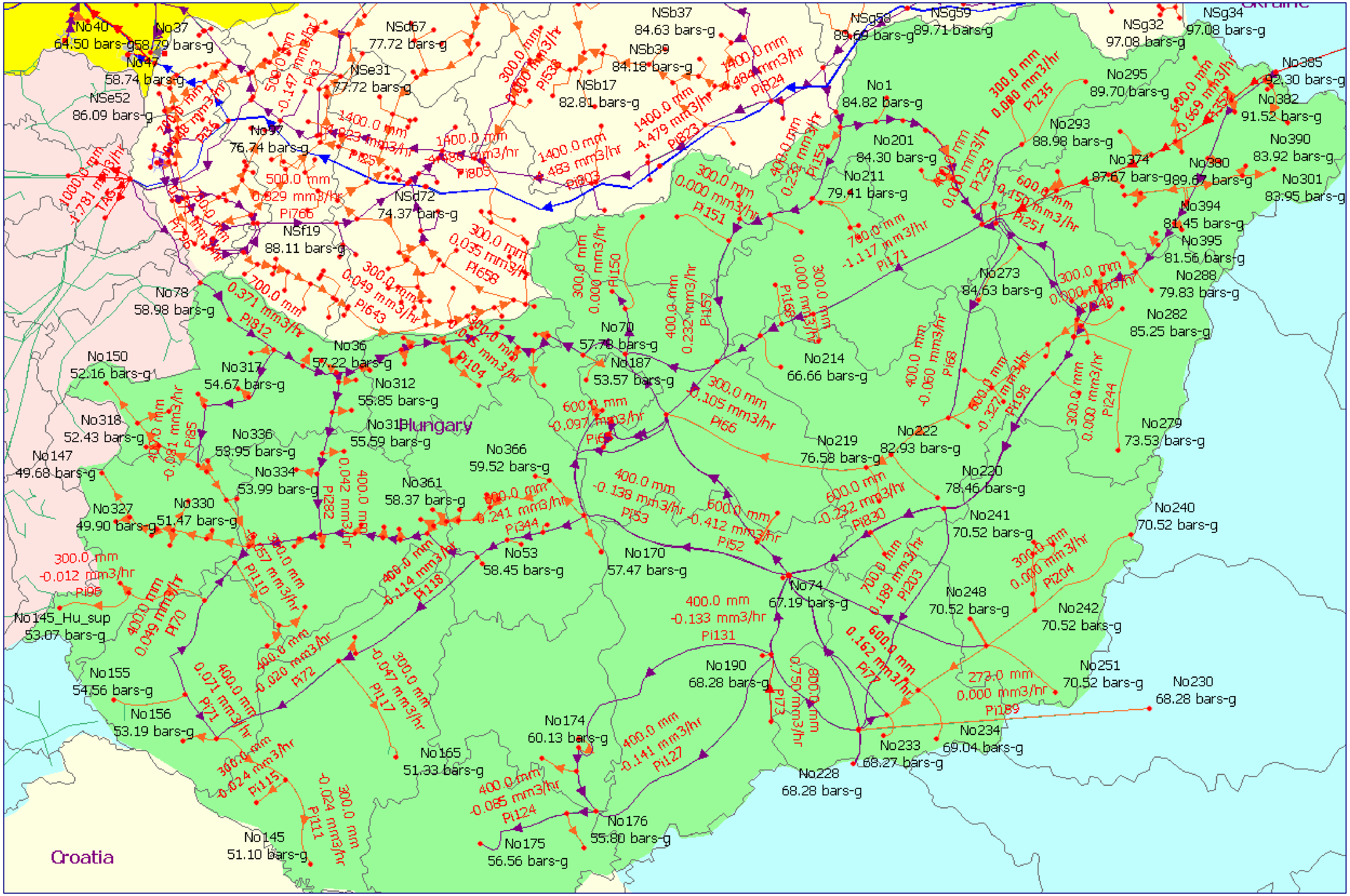


Figure A5.3 : Hungary pipeline model

APPENDIX VI : Gas consumption and population data

It was considered necessary to have a strategy to calculate the distribution of gas demand flow rates throughout the three countries. This was based on population distribution and some assumptions about the load distribution between domestic and industrial customers. The following describes the method adopted using the Czech Republic as an example.

General gas data

Some basic representative gas data for the Czech Republic is shown in Table A6.1. The maximum storage supply flow rate is deduced from a histogram provided in the October 2005 Ten-e report. The sum of individual store flow rates compiled from the 2002 IEA report gives a lower figure of 1.18 mm^3/hr. The supplies into the system from individual stores was compiled from available data and known geographical locations of the stores.

A peak winter demand for January of 14.38% of annual load was derived from curve fitting to the 2002 IEA report data. Alternative curve fitting approaches gave values of between 14.23 and 14.43%. This was then translated into an hourly flow rate of 2.7mm^3/hr as derived in the next section. Production, export and import consumptions were taken from the ENI web site data for 2004. This global data was required to assist in distributing the gas load throughout the system.

Table A6.1
Basic gas data for the Czech Republic

Czech Republic	bcm/year	mm^3/hr	Comment on hourly rate
Storage (Capacity=3.2bcm)	////	2.08	Based on daily rates
Consumption	9.69	2.70	Peak winter flow rate (Jan)
Production	0.26	0.03	Annual divided by hours in year
Export	0.1	0.01	Annual divided by hours in year
Import	9.8	1.12	Annual divided by hours in year

Note: Selection of the “peak winter flow rate“ is an important parameter that is discussed below.

Daily gas consumption profiles

Gas consumption may be divided into domestic, commercial, industrial and power production sectors. It may also be considered to be partly ambient temperature dependent and partly independent. However, the proportions are not known and assumptions have been made. Table A6.2 shows the distribution of consumption from two sources, IEA and Eurogas. Two cases (Options 1 & 2) were considered for apportioning gas load between users and considering the effects of temperature using the Eurogas data.

For the SynerGee model hourly flow rates are required so it is necessary to determine the number of hours over which the total January demand is distributed ie. the number of operating hours for each type of user. Domestic heating is usually controlled by time clock, so in the first instance, 16 hours per day was selected. Similarly, 16 hours was selected for meeting peak demand electrical power. With regard to industrial and “other” power consumption some may be used in 24-hour continuous processes (eg. glass production) whilst some will be used for factory heating etc. ie. in a similar load profile to domestic heating.

In the first case, an assumption was made that domestic and commercial consumption (49.2%) relates to heating that is on for 16 hours per day whilst combined power, industry and other uses (50.8%) relates to continuous 24 hour usage. This produced a maximum flow rate of 2.34 mm^3/hour which was then divided amongst the various regions. The detail is shown in Table A6.3, Option 1, that also shows that the resulting calculated consumption per customer is a reasonable working value, although it could still be significantly in error.

Table A6.2
Options for distribution of gas load between end users

Data source	% distribution of gas consumption between users				
	Domestic/ commercial	Power	Industry	Other	Total as %
Assumption >	Temperature dependent		Temperature independent		
IEA 02	43	9	35	13	100
Eurogas 03	49.2	15.8	31.3	3.7	100
Option 1 Eurogas 03	49.2	50.8			100
Option 2 Eurogas 03	65.0		35.0		100

In the second case, an assumption was made that gas used for electrical power generation is used for peak demand rather than base load, and is therefore temperature dependent and domestic demand is used for heating and is therefore primarily also temperature dependent. Industrial consumption and "other" undefined consumption were considered to be temperature independent. Using the Eurogas data this gives 65% of the load as temperature dependent and 35% as temperature independent. Of the independent load 40% was considered to be continuous (24hour) and 60% used for16 hours per day. This produced a maximum flow rate of 2.69 mm^3/hr, (see Table A6.3 for further details) that was again distributed amongst the regions on a proportional basis.

It is important to note that the selection of total operating time will significantly affect the overall flow rates used in the model and the choice of 16 hours may be incorrect by perhaps a factor as large as 2. Increased flow rates will lead to significant increases in pipeline pressure drops and will result in the need for more compressor station power to be available, so this factor is key and must be examined in greater detail when assessing the sensitivity of the overall model.

Population distribution
For the Czech Republic, population data and number of dwellings per region were taken from ARC 2004 shape file data. The data is also available from the open source shape files identified in Table A2.4. This data is shown reproduced in the SynerGee environment in Figure A6.1. For comparison, the overall data from the UN statistics for 2005 are 0.3% lower. The number of gas customers (domestic and industrial) was taken from the Eurogas annual report for 2003. The number of customers geographically distributed was assumed to be the same as the percentage distribution for dwellings (not population). Similarly the distribution of industrial consumption was taken to be the same percentage, but there is no real justification for this. Hence the domestic and industrial gas consumption per region was calculated as shown in Table A6.4.

Finally, the distribution of the load by region was then apportioned to the known outlets in the transmission system in a proportional manner based on the maximum flow rates given by RWE for their outlet pressure reduction stations. (This information is supplied on a map of the RWE system supplied to the JRC). The result is shown in detail in Table A6.5. Such information is not however available for the other two countries, so load was distributed on a "number of dwellings" only proportional basis.

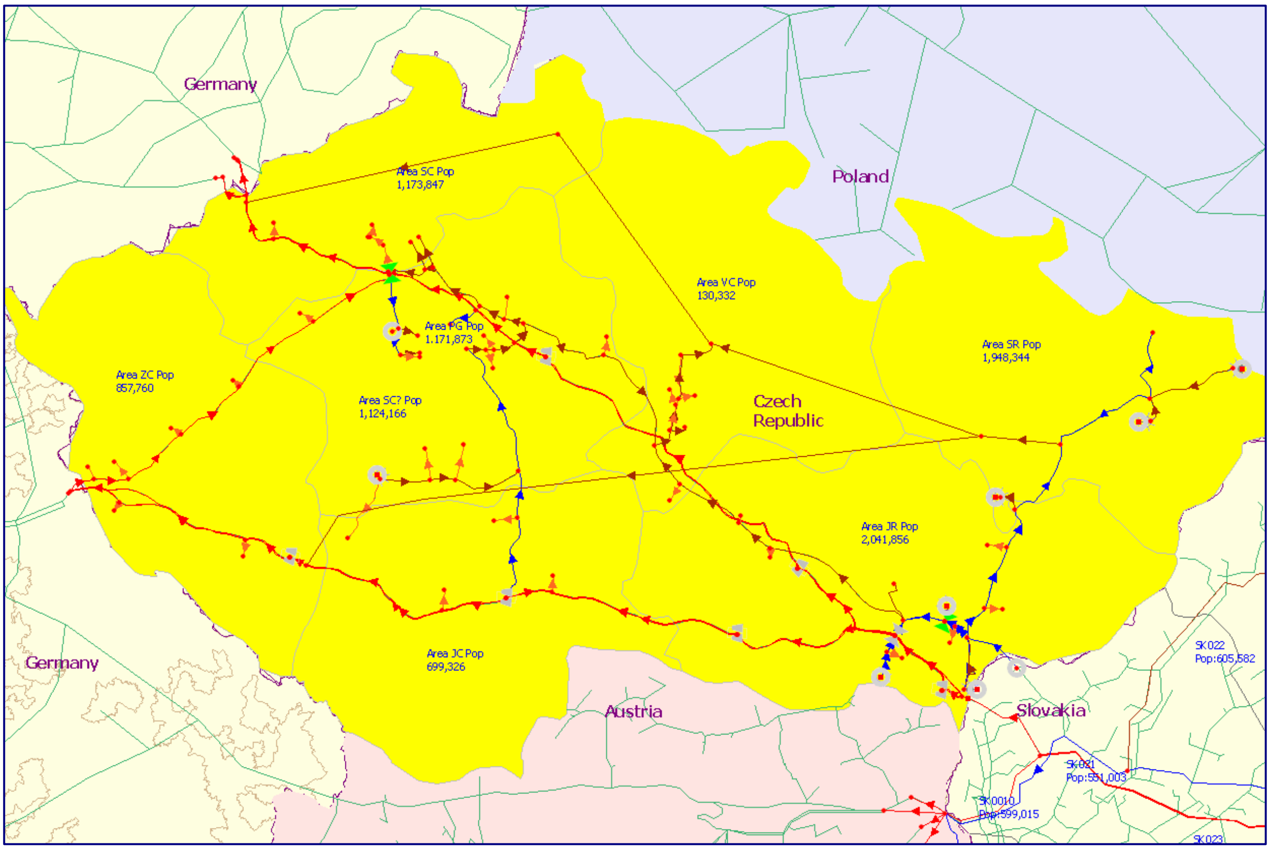


Figure A6.1: Population by region in the Czech Republic

Table A6.3
Estimate of gas consumption by customer category

Parameters Option 1	% of annual load in January	Data source	Gas customers: Domestic details	Gas customers: Industrial + power+other details			Overall totals
Peak consumption (Jan) as % of annual	14.38	IEA 2002					
% of total load	-		49.2	50.8			100
Assume no. of hours **X** /day for supply		**X hrs =>>**	**16**	**24**			-
No.of customers & % of total population		Eurogas 2003	2,564,300	173,400			2,737,700
Annual consumption (PJ)			181.8	187.9			
Conversion of consumption to bm^3 gas			4.78	4.94			9.72
Jan.flow rate mm^3/hr (divided between dom/ind)			1.386	0.955			2.341
Consumption/customer in Jan. m^3			268.13	4098.19			-
Consump./customer m^3/hr (Dom.**X** hr day; Ind 24hr)			0.54	5.51			-
Consumption/customer (kw)			5.71	58.22			-
Parameters Option 2	**Y% constant load for Ind. + other**	**Data source**	**Domestic+Power Temperature dependent**	**Industrial+other Partly temperature independent**			**Overall totals**
% of total load			65	35			100
Assume (1-**Y**)% of ind/power for (**X**) hrs; **Y**% for 24 hr	40.0	**X hrs =>>**	**16**	**24**	**16**	**Total**	-
Annual consumption (PJ)	-	Eurogas 2003	240.2	51.8	77.7	129.5	369.70
Conversion of consumption to bm^3 gas			6.32	1.36	2.04	3.41	9.72
Jan.flow rate mm^3/hr (divided between 65% & 35%)		-	1.831	0.263	0.592	0.86	2.69
Consumption/customer in Jan. m^3			354	1130	1695	2824	-
Consump./customer m^3/hr (Dom.**X** hr day; Ind. mixed hr)			0.71	1.5	3.4	4.9	-
Consumption/customer (kw)			7.55	16.1	36.1	52.2	-

Table A6.4: Population and gas consumption assumptions by region for the three countries

Country	Region	Abbrev.	Population	Area	Population	Dwellings	%	Pop per	No. of gas customers			Consump.(mm3)/hr/region		Total flow	No. of
	Name	letters	No.	km2	Density	No.	dwellings	dwelling	Domestic	as %	Ind.	Domestic	Ind.	Dom+Ind	Offtakes
Czech Republic	Severomoravsky	SR	1,948,344	10,934	177	774,171	16.3	2.517	418,077.5	16.3	28,270.7	0.299	0.140	0.438	7
	Jihomoravsky	JR	2,041,856	14,858	136	816,268	17.2	2.501	440,811.2	17.2	29,808.0	0.315	0.147	0.462	7
	Vychodocesky	VC	1,230,332	11,103	110	530,550	11.2	2.319	286,514.2	11.2	19,374.3	0.205	0.096	0.300	9
	Stredocesky	SC?	1,124,166	10,868	103	497,708	10.5	2.259	268,778.5	10.5	18,175.0	0.192	0.090	0.282	8
	Praha	PG	1,171,873	491	2,365	550,909	11.6	2.127	297,508.8	11.6	20,117.8	0.212	0.099	0.312	5
	Jihocesky	JC	699,326	11,216	62	699,326	14.7	1.000	377,658.8	14.7	25,537.6	0.270	0.126	0.396	4
	Zapadocesky	ZC	857,760	10,746	79	370,072	7.8	2.318	199,850.9	7.8	13,514.1	0.143	0.067	0.209	7
	Severocesky	SC	1,173,847	7,716	151	509,414	10.7	2.304	275,100.1	10.7	18,602.5	0.196	0.092	0.288	9
	Totals from above		**10,247,504**	**77,932**	**131**	**4,748,418**	**100**		**2,564,300**	**100**	**173,400**	**1.831**	**0.856**	**2.687**	**56**
Slovakia	Bratislavský kraj	SK010	599,015	2,036	294.3	243,993	12.9	2.455	183,198.6	12.9	128.7	0.134	0.095	0.229	9
	Trnavský kraj	SK021	551,003	4,095	134.5	191,654	10.1	2.875	143,900.6	10.1	101.1	0.106	0.074	0.180	24
	Trencianský kraj	SK022	605,582	4,505	134.4	220,841	11.6	2.742	165,815.3	11.6	116.4	0.122	0.086	0.207	18
	Nitrianský kraj	SK023	713,422	6,254	114.1	265,394	14.0	2.688	199,267.2	14.0	139.9	0.146	0.103	0.249	33
	Zilinský kraj	SK031	692,332	6,825	101.4	231,879	12.2	2.986	174,103.0	12.2	122.3	0.128	0.090	0.218	15
	Banskobystrický kraj	SK032	662,121	9,390	70.5	255,803	13.5	2.588	192,066.0	13.5	134.9	0.141	0.099	0.240	22
	Presovský kraj	SK041	789,968	9,040	87.4	232,770	12.3	3.394	174,772.0	12.3	122.7	0.128	0.090	0.219	28
	Kosický kraj	SK042	766,012	6,732	113.8	254,220	13.4	3.013	190,877.4	13.4	134.0	0.140	0.099	0.239	23
	Totals from above		**5,379,455**	**48,877**	**110**	**1,896,554**	**100**		**1,424,000**	**100**	**1,000**	**1.045**	**0.735**	**1.781**	**172**
Hungary	Vas	VAS	275,813	3,392	81.3	102,372	2.5	2.694	76,417.7	2.5	4,578.0	0.089	0.023	0.111	9
	Gyor-Moson-Sopron	GSP	424,352	4,009	105.8	164,440	4.0	2.581	122,749.6	4.0	7,353.7	0.142	0.037	0.179	10
	Veszpren	VSZ	383,366	4,611	83.1	141,801	3.5	2.704	105,850.2	3.5	6,341.3	0.123	0.031	0.154	12
	Zala	ZAL	309,836	3,863	80.2	117,363	2.9	2.640	87,608.0	2.9	5,248.4	0.102	0.026	0.128	5
	Somogy	SMG	344,122	6,012	57.2	130,795	3.2	2.631	97,634.6	3.2	5,849.1	0.113	0.029	0.142	7
	Komarom-Esztergom	KMR	313,627	2,230	140.6	120,158	3.0	2.610	89,694.4	3.0	5,373.4	0.104	0.027	0.131	9
	Fejer	FEJ	419,426	4,440	94.5	160,485	3.9	2.613	119,797.3	3.9	7,176.8	0.139	0.036	0.175	8
	Tolna	TOL	256,833	3,688	69.6	96,232	2.4	2.669	71,834.3	2.4	4,303.4	0.083	0.021	0.105	3
	Baranya	BRN	415,919	4,402	94.5	156,632	3.8	2.655	116,921.1	3.8	7,004.5	0.136	0.035	0.170	3
	Pest	PES	2,855,206	6,465	441.7	394,280	9.7	7.242	294,318.3	9.7	17,632.0	0.342	0.088	0.429	10
	Budapest	BDP	1,777,921	512	3475.6	821,450	20.2	2.164	613,188.1	20.2	36,734.8	0.712	0.182	0.894	8
	Bacs-Kiskun	BKS	545,800	8,291	65.8	230,362	5.7	2.369	171,958.4	5.7	10,301.7	0.200	0.051	0.251	15
	Nograd	NGR	231,528	2,417	95.8	88,111	2.2	2.628	65,772.2	2.2	3,940.3	0.076	0.020	0.096	5
	Heves	HEV	337,044	3,594	93.8	129,705	3.2	2.599	96,820.9	3.2	5,800.3	0.112	0.029	0.141	5
	Jasz-Nagykun-Szolnok	SZL	435,609	5,673	76.8	208,023	5.1	2.094	155,283.0	5.1	9,302.7	0.180	0.046	0.226	8
	Csongrad	CSN	431,159	4,187	103.0	182,031	4.5	2.369	135,880.7	4.5	8,140.3	0.158	0.040	0.198	6
	Bekes	BEK	416,617	5,582	74.6	165,052	4.1	2.524	123,206.4	4.1	7,381.0	0.143	0.037	0.180	5
	Borsod-Abauj-Zemplen	BAZ	777,201	7,235	107.4	279,672	6.9	2.779	208,766.9	6.9	12,506.8	0.242	0.062	0.304	8
	Hajdu-Bihar	HBI	548,097	6,156	89.0	212,533	5.2	2.579	158,649.6	5.2	9,504.4	0.184	0.047	0.231	9
	Szabolcs-Szatmar-Bereg	SSZ	588,856	6,024	97.8	168,323	4.1	3.498	125,648.1	4.1	7,527.3	0.146	0.037	0.183	19
	Totals from above		**12,088,332**	**92,782**	**130**	**4,069,820**	**100**		**3,038,000**	**100**	**182,000**	**3.526**	**0.904**	**4.430**	**164**

Table A6.5

Calculation used for distribution of gas load in the Czech Republic

No. of supplies	Name of region	Abbrev-iation Letters	Population No.	Area km^2	Population Density / km^2	No. of Dwellings	Pipe System Nodes No.	Pipe System Nodes Name	Max. flow mm^3/hr	% of total in region	Regional* max. flow mm^3/hr
1							NCs01	Ostrava	0.2	16.9	0.074
2							NCs03	Tranovice	0.08	6.8	0.030
3							NCs05	Stramberk	0.2	16.9	0.074
4	Severomoravsky	SR	1,948,344	10,934	177	774,171	NCs07	Stramberk2	0.2	16.9	0.074
5							NCs11	Lobodice	0.2	16.9	0.074
6							NCs13	Nr Lobodice	0.2	16.9	0.074
7					Supply details assumed		NCs09	Olomouc	0.1	8.5	0.037
7	Total - Severomoravsky								**1.18**	**100**	**0.438**
1							NCj32	Ulrice-s	0.2	16.8	0.078
2							NCj01	Velkes M1	0.2	16.8	0.078
3							NCj03	Velkes M2	0.2	16.8	0.078
4	Jihomoravsky	JR	2,041,856	14,858	136	816,268	NCj33	Ostrana-s	0.15	12.6	0.058
5							NCj35	Ostrana-s	0.2	16.8	0.078
6							NCj28	Ulrice-s	0.08	6.7	0.031
7	Bruno						NCj21	No.10_ Bruno	0.08	6.7	0.031
8							NCj13	Ddunja-s	0.08	6.7	0.031
8	Total - Jihomoravsky								**1.19**	**100**	**0.462**
1							NCv03	Olesna1	0.2	12.2	0.037
2							NCv12	Hradec Kralove-a	0.2	12.2	0.037
3							NCv11	Hradec Kralove-b	0.2	12.2	0.037
4							NCv06	Olesna-s	0.2	12.2	0.037
5	Vychodocesky	VC	1,230,332	11,103	110	530,550	NCv05	Olesna2	0.08	4.9	0.015
6							NCv08	Olesna5	0.08	4.9	0.015
7							NCv07	Olesna-s	0.2	12.2	0.037
8							NCv10	Olesna7	0.08	4.9	0.015
9							NCv01	Jihlava	0.4	24.4	0.073
9	Total - Vychodocesky								**1.64**	**100**	**0.300**
1							NCa03	Hospozin	0.2	16.7	0.047
2							NCa08	Usti4	0.2	16.7	0.047
3							NCa10		0.2	16.7	0.047
4							NCa28	Krupa	0.16	13.3	0.038
5							NCa18	Kutna Kora-s	0.2	16.7	0.047
6	Stredocesky	SC(a)	1,124,166	10,868	103	497,708	NCa24	Haje-s	0.08	6.7	0.019
7							NCa22	Haje-s	0.08	6.7	0.019
8							NCa32	Limuzy_a	0.08	6.7	0.019
8	Total -Stredocesky								**1.2**	**100**	**0.282**
1							NCp01	Praha_N	0.2	16.7	0.052
2							NCp02	PS_Limuzy_b	0.2	16.7	0.052
3							NCp03	Praha_E	0.2	16.7	0.052
4	Praha	PG	1,171,873	491	2,365	550,909	NCp05	Praha_W_c	0.2	16.7	0.052
5							NCp04	Praha_W_d	0.2	16.7	0.052
6							NCp06	Praha_W_e	0.2	16.7	0.052
6	Total - Praha								**1.20**	**100.00**	**0.312**
1							NCb01	Haje-s	0.08	13.8	0.055
2	Jihocesky	JC	699,326	11,216	62	699,326	NCb11	Zverkovice	0.15	25.9	0.102
3							NCb05	Lodherov	0.15	25.9	0.102
4							NCb03	Praha-s	0.2	34.5	0.136
4	Total - Jihocesky								**0.58**	**100**	**0.396**
1							NCc01	PS_Rozadov	0.08	10.1	0.021
2							NCc07	PS_H.Hradiste	0.2	25.3	0.053
3							NCc03	PS_Bor	0.08	10.1	0.021
4	Zapadocesky	ZC	857,760	10,746	79	370,072	NCc05	Svinomazy	0.2	25.3	0.053
5							NCc17	Bela	0.15	19.0	0.040
6							NCc15	Nr Strazovice	0.08	10.1	0.021
6	Total - Zapadocesky								**0.79**	**100**	**0.209**
1							NCd01	Usti1	0.08	7.3	0.021
2							NCd03	Usti2	0.2	18.3	0.053
3							NCd04	Usti3	0.15	13.8	0.040
4	Severocesky	SC(b)	1,173,847	7,716	151	509,414	NCd10	Hosp-s	0.2	18.3	0.053
5							NCd09	Hosp-s	0.08	7.3	0.021
6							NCd08	PS_Hora	0.08	7.3	0.021
7					Supply details assumed		NCd11	Liberec	0.1	9.2	0.026
8							NCd05	Bylany	0.2	18.3	0.053
8	Total - Severocesky								**1.09**	**100**	**0.288**
56.00	**Total of maximum available local flows as supplies/sinks from system**								**8.87**		**2.687**

* Regional loads calculated in Table A6.4

APPENDIX VII : Example reports from SynerGee

Unknown Node Flows (mm3/hr)	
Node Name	**Node Flow**
No11_DDunajovice	0.473
No70_Tvrdonice	0.278
No69_Stramberk	0.241
No09_Uhrice	0.239
No109_Haje	0.221
No60_Lobodice	0.124
No20_Import_Lanzhot	0.109
No68_Tranovice	0.097

Supplies and Demands		
Sum of System Demands	-18.485	mm3/hr
Sum of System Supplies	18.525	mm3/hr
Sum of Compressor Fuel	0.04	mm3/hr
Demands	0	mm3/hr

Exception Report for Highest Pressures Below (566.00bars-g)		
Node Name	**Pressure Primary Units (bars-g)**	**Pressure Secondary Units ()**
Data Not Available		

Nodes with the Highest Pressures (bars-g/Pa)	
Node Name	**Pressure**
No69	160.08
No31	146.01
No95	141.19
No123-Hajd	136.26
No66	135.23
No113	134.23
No35	127.28
No117-Zsana	126.12
No122-Kardoskut	125.65

Nodes with the Lowest Pressures (bars-g/Pa)	
Node Name	**Pressure**
No99_Jihlava	50.55
No90_Usti1	50.64
No78_Olesna_5	51.03
No79_Olesna-s	51.08
No17_Hradec Kralove-a	51.09
No80_Hradec_Kralove_b	51.15
No125_Olesna7	51.34
No124	51.4
No34_Export_Olbernhau	51.61

System Performance Indices	
Index Name	**Index Value**
M3/hr - KM INDEX	11863308258
MM-KM/M3/hr INDEX	0.434569

Flow Sink Nodes
Data Not Available

Exception Report for Non-Pipe Facility Flow Reversals				
Facility Name	**From Node**	**To Node**	**Type**	**Flow (mm3/hr)**
Va_Hospozin_b	No72	No73_Hospozin	GV	-0.145
Va31	No38_Ulrice-s	No39	GV	-0.089

Exception Report for Lowest Pressures Above (100.34bars-g)		
Node Name	**Pressure Primary Units (bars-g)**	**Pressure Secondary Units ()**
No99_Jihlava	50.55	
No90_Usti1	50.64	
No78_Olesna_5	51.03	
No79_Olesna-s	51.08	
No17_Hradec Kralove-a	51.09	
No80_Hradec_Kralove_b	51.15	
No125_Olesna7	51.34	
No124	51.4	
No34_Export_Olbernhau	51.61	

Pipes with the Highest Headloss (kPa^2/km)						
Pipe Name	From Node / To Node	Headloss (kPa^2/km)	Diameter (mm)	Length (km)	Pressure (bars-g/Pa) From	To
Pi80	No123-Hajd / No35	3747640.5	285.8	6.4	136.26	127.28
Pi58	No90 / No31	783769.6	1355.2	125.6	146.01	107.49
Pi101	No151 / No111	738519.1	285.8	26.8	96.85	86.17
Pi24	No34 / No90	716443.1	1355.2	4.1	107.49	106.12
Pi69	No115 / No44	521629.2	382.6	38.6	115.3	106.29
Pi83	No103 / No111	469769.3	285.8	34.6	104.83	96.85
Praha_S3	No136_Praha-s / No137	456579.3	285.8	8.5	65.17	62.16
Pi104	No153 / No154	433309.7	285.8	20.9	104.85	100.48
PS_Hospozin_3	No90_Usti1 / No16	420926.5	138.8	4.8	52.56	50.64

Pipes with the Highest Velocity (m/s)						
Pipe Name	From Node / To Node	Velocity (m/s)	Diameter (mm)	Length (km)	Pressure (bars-g/Pa) From	To
Pi_Import_ Lanzhot	No48_Lanzhot border / No20_Import_Lanzhot	-22.3	1354.2	0	63	62.99
Pi21	No20_Import_Lanzhot / No42	-22	1355.2	35.7	72.66	63
Pi58	No90 / No31	-18.1	1355.2	125.6	146.01	107.49
Pi22	No37 / No44_C_Breclav_In	-17.4	1354.2	0	62.33	62.32
Pi24	No34 / No90	-17.4	1355.2	4.1	107.49	106.12
Pi35	No60_C_Breclav_Out / No40	-16.8	1354.2	0	64.5	64.49
Hostim CS supply	No62_C_Hostim_In / No35_C_Hostim_In2	-16.6	1354.2	0.1	57.4	57.39
Pi31	No62_C_Strazovice_In / No36_C_Strazovice_In2	-15.1	1354.2	0.1	55.75	55.74
Pi29	No60_C_Veselie_In / No35_C_Veseli_In2	-14.4	1354.2	0.1	64	63.99

Pipes with the Highest Pack Volumes (Msm^3)						
Pipe Name	From Node / To Node	Linepack (Msm^3)	Diameter (mm)	Length (km)	Pressure (bars-g/Pa) From	To
S_bot_b	No35_C_Veseli_In2 / No31_C_Hostim_Out2	994	13954.2	87.2	64	64
Pi25	No33 / No34	74.7	1355.2	433.9	106.12	85.03
Pi33	No42 / No34	62.1	1355.2	387.1	106.12	72.66
Pi34	No42 / No34	45.1	1155.2	387.1	106.12	72.66
Pi58	No90 / No31	30.2	1355.2	125.6	146.01	107.49
Pi60	No95 / No69	15.2	768.2	162.8	160.08	141.19
Pi42	No66 / No95	10.1	768.2	119.3	141.19	135.23
S_bot_a	No35_C_Hostim_In2 / No60_C_Breclav_Out	9.2	1354.2	90.8	64.49	57.4
S_bot_c	No36_C_Strazovice_In2 / No69_C_Veseli_Out2	8.9	1354.2	87.1	67	55.75

Total System Line Pack Volume = 1481.5 (Msm^3)

APPENDIX VIII: Acronyms

Acronym	Detail
AGI	Above Ground Installation
CIS	Commonwealth of Independent States
EPCIP	European Program on Critical Infrastructure Protection
ERGEG	European Regulators Group for Electricity & Gas
Eurogas	The European union of the natural gas industry
GIE	Gas Infrastructure Europe
GIS	Graphical Information System
GLE	Gas LNG Europe
GSE	Gas Storage Europe
GTE	Gas Transmission Europe
IEA	International Energy Agency
JRC	Joint Research Centre (EC)
LNG	Liquefied Natural Gas
IPSC	Institute for the Protection and Security of the Citizen
PE	Petroleum Economist
PIPESECURE	JRC Pipeline Security project
PRESENSE	EC FP5 project “Pipeline Remote Sensing for Safety and the Environment”
SARES	Security And Reliability of Energy Supplies (Activity Area)
SMYS	Specified Minimum Yield Strength
SYNERGEE	Commercial name of pipeline modelling software package
VASTS	Vulnerability Assessment and Surface Transport Security
VATDIS	Vulnerability Assessment in Transport Distribution Systems

APPENDIX IX : Support Information Requested from Operators

European Critical Gas Infrastructure modelling

A one-day workshop at the JRC

September 2007

A European Gas Transmission Pipeline Model

Support Information Requested from Operators

A European Gas Transmission Pipeline Model
Support Information Requested from Operators

Background

To support studies related to the European Programme on Critical Infrastructure Protection (EPCIP) the JRC (Joint Research Centre) of the EC is developing a model of the high pressure gas pipeline infrastructure. It is anticipated that the model will provide further insight into the most important physical parameters of the system enabling informed discussion on a key sector of the European energy infrastructure.

Objective

Many organizations will already have detailed analytical models of their own infrastructures, but will not necessarily have a detailed model of connecting infrastructures in other countries or owned by other organizations. From the European perspective the interest for EPCIP of a gas pipeline model is to identify potentially weak physical links (as opposed to economic, market or IT related factors) in the supply chain.

The model at present comprises data for three neighbouring countries, viz:- The Czech Republic; Hungary and Slovakia. The choice of countries was simply that they were linked to one of the major gas transmission supply routes to central Europe. It is anticipated that the present model is sufficiently large that it will be able to test the hypothesis that that any benefits and improved understanding can be established (or otherwise) without the need for introducing further countries at this stage of its development.

Results

The model will need to be run over a range of different scenarios. In order to optimize the time spent and the quality of the outputs it is desirable to achieve a consensus of opinion on the parameters used within the model. Your organization is invited to participate in this exercise by providing non-confidential information in support of the model development.

Any data provided will be considered for use within the model and the general results from the model will be made available to all participating organizations. However, the details of your selections will not be made available or shared with other organizations, nor will any item that is considered by your organization to be commercially sensitive be transferred to other organizations. In the first instance, results from the model incorporating data supplied by companies that may be shared on a common basis are as indicated in Figure 2 and Table 17.

The objective is to examine the system performance under extended extreme conditions rather than normal operating conditions – ie. conditions most likely to occur under severe weather conditions.

The Questionnaire

In your opinion for your pipeline system in your country, please can you supply the following support information to the attached questionnaire? The data refers to the high pressure gas transmission system only and not to any low pressure distribution system. It is noted that even this statement may require further definition as different countries adopt different protocols to define boundaries of their systems. In order to make the model as universally simple as possible, it is desirable to use common values of parameters wherever possible. Therefore the following sections identify the main areas of interest, the assumptions used in the model to date and provide space for agreements/disagreements or your inputs.

Conclusion

I would like to thank your organization for participating in this exercise.

Yours sincerely

Russell Pride
On behalf of the JRC, Ispra, Italy

Legal Notice

1.0 Your details

Please supply your company and author details in the header section above.

2.0 Gas and general properties

The general properties used in the model are provided in Table 1 and apply to all countries and gas flows. Please review for your pipeline system and add any suggestions.

Table 1
Gas and general properties

Feature	Item	Value	Units	Agree Y = Yes N = No	Alternative proposal	Comment Reference a, b, c, etc.
Gas properties	Flow temperature	15.5	^oC			
	Heat content	37.26	Mj/m^3			
	Specific gravity	0.6	-			
	CO2 content	0.5	-			
	Viscosity	0.01197	cP			
Ambient conditions	Temperature	15.5	^oC			
	Pressure	1.0156	Bar			
	Elevation	0	m			

Comments
a.
b.

3.0 Pipelines

As a general indication of the pipeline layouts used in the 3-country model refer to Appendices I, II and III. At the magnification of these images the full details of all pipelines, the number of pipelines in multi-pipeline right of ways or the specific details of each pipeline are not shown. Appendices IV and V provide further detail on pipeline diameters where there are multiple pipelines in a Right Of Way (ROW). The pipelines have been geo-located using the Platts database with pipe lengths and locations probably within the order of a 1-2km using WGS_1984. A few additional pipelines from the Petroleum Economist pipeline maps have also been added but not geo-located as they appear to be only indicative of location.

3.1 Pipeline nodes

Where a change in a facility occurs (for example a connection to a compressor station) a Node is introduced. Nodes are shown as red dots on the maps in the Appendices. Note that at the appendix map scale it is not possible to show the reference name of most nodes. Nodes are also shown at connections between pipes and even when there is a change in say pipeline diameter. Viewing these maps at increased magnification on your pc will help distinguish exactly where the nodes are. (An electronic version of this questionnaire will be sent to you)

At some locations where pipes cross it is not clear from the database whether there is a real connection. If a node is shown in the appendix maps then a connection has been made in the model. Please review the map and identify where possible any nodes that should or should not be there. This may not be possible with the available resolution from the supplied maps, particularly where there are multiple pipelines in the same Right of Way. If there are issues over this then we need to find an alternative way of clarifying the situation. For example each area of uncertainty could be presented as individual maps.

Comments	Number	Map supplied	
		Yes	No
Number of incorrect node connections (Indicated by red circles to be added on the map)			
(Indicated by red circles to be added on the map) (Indicated by blue coloured circles to be added on the map)			

3.2 Wall thickness

Pipelines across Europe have been installed over the last 50 years to many different standards. Please review Table 2 which is the data used in the current model. Basic pipe sizes were taken from the Platt's data base which were assumed to be the external diameter and in inches. Where available these were rounded to the nearest whole number diameter in mm. Finally a limited set of pipe diameters was chosen based on C4Gas data from 2004. The table shows the final external diameters in mm and their selected internal diameters. Values for SMYS are discussed in the next section.

To indicate distribution outlets where no data was available 300mm pipe was selected and an arbitrary short length shown on the map. There are many more pipeline diameters and wall thicknesses that could have been selected, the selection is a compromise.

Table 2
Selected pipeline diameters and wall thicknesses used in the model

Nominal external Diameter		Wall Thickness	Internal Diameter	Pipe Grade	SMYS* calculated	Maximum* Pressure	Agree	Alternative proposal	
Inch	mm	mm	mm	X -	Bar	Bar	Y=Yes N=No	Diameter mm	Wall mm
5.9	150.0	5.6	138.8	42.0	2857.1	128.0			
8.7	220.0	6.4	207.2	42.0	2857.1	99.7			
11.8	300.0	7.1	285.8	60.0	4081.6	115.9			
15.7	400.0	8.7	382.6	60.0	4081.6	106.5			
19.7	500.0	11.9	476.2	60.0	4081.6	116.6			
23.6	600.0	14.3	571.4	60.0	4081.6	116.7			
27.6	700.0	11.9	676.2	60.0	4081.6	83.3			
31.5	800.0	15.9	768.2	60.0	4081.6	97.3			
35.4	900.0	17.5	865.0	65.0	4421.8	103.2			
39.4	1000.0	19.1	961.8	65.0	4421.8	101.3			
47.2	1200.0	22.4	1155.2	65.0	4421.8	99.0			
55.1	1400.0	22.9	1354.2	80.0	5442.2	106.8			

* - see next section.

Comments

3.3 Maximum operating pressures

Although individual pipeline operating pressures or flows could be assigned as boundary conditions, these have not as yet been used in the model. They would provide one of the indicators of system operating limits. Different countries adopt different methods of calculating maximum operating pressures, some risk analysis being extremely complex. To give a simple indication of the SMYS and maximum operating pressures for these diameters one approach is to use a US method using the formula below:-

$$P = \{2 \times t \times S \times (E \times F \times T)\} / D \quad \text{……………………. (i)}$$

Where:-

P = Pressure (Bar) t = wall thickness (mm)
D = Diameter (mm) S = SMYS (Specified Minimum Yield Strength)

and design de-rating factors are:-

E = Seam joint factor (taken as 1 for this analysis)
F = Class factor (conservatively taken as 0.6 from Table 3 below)
T = Temperature de-rating factor (taken as 1 for this analysis)

Table 3
Class factors for de-rating pipelines

Class	**Factor**	**Location or distance either side of pipe centre line**	**Number of dwellings per unit length**		**Number of dwellings per unit area**		**Land area per dwelling**	
			No./mile	**No./km**	**No./mile^2**	**No./km^2**	**yds^2**	**m^2**
1	0.7	Offshore & rural	<10	16	40	15	77,440	64,750
2	0.6	Within 220yds (201m)	<46	74	184	71	16,835	14,076
3	0.5	Within 220yds (201m)	>46	74	184	71	16,835	14,076
4	0.4	Towns & cities	Urban	-	-	-	-	-

These values have been included in the calculations used in Table 2 as examples.

It is not the intention of the model to deal in any way with risk assessments of different sections of pipeline, only the end flow rate is of importance. None the less a common strategy would be desirable for as many groups of pipes as possible. Within the software model it is possible to edit groups of facilities at the same time with a common change. eg. increase all pipelines maximum pressure by x%. Therefore it is desirable to group pipelines in some common way. Please review Table 4 and comment on pipeline pressure ratings.

Table 4
Calculation of pipeline pressure ratings

Is approach for calculating maximum pressures considered acceptable for a simple model?	Yes		No	
An alternative approach is proposed as indicated in attachment	Yes		No	
Would your company consider supplying real pipeline maximum pressures or de-rating factors for all or some pipelines?	Yes		No	

Comments

3.4 Pipeline flow equations

For simplicity the current model uses the Mueller flow equation and a 100% value for efficiency. (See presentation material). Values for roughness or friction factor are not required. Pigging and other source data often indicate the need for de-rating factors. These could be accommodated by introducing a reduced efficiency factor that may need to be set for individual pipelines. Also pipe elevation does not enter into the equation. If more specific equations are used then values are required. Initial indications from overlaying the pipelines onto Google Earth suggest that in general pipelines in the selected countries do not have large elevation changes, but this would not be the case in an extended model covering other European countries. Please look at Table 5 and either agree to the values currently proposed or enter preferred values used in your organization if a more detailed flow equation were to be introduced. Please add any further explanation required.

The Mueller flow equation used in the model is shown below.

$$Q = 2.489 \times 10^{-9} \times E \times SG^{-0.425} \times D^{2.725} \times [(P_{in}^2 - P_{out}^2)/ L]^{0.575} \;\ldots\ldots\ldots\ldots\; \text{(ii)}$$

Where:-

Q = Flow rate (millions of m^3/hr - mm^3/hr)
SG = Specific gravity of the gas
P_{in} = Inlet pressure (Bar)
P_{out} = Outlet pressure (Bar)
E = Efficiency
D = Internal pipeline diameter (mm)
L = Pipeline length (km)

Table 5
Pipeline properties

Property	Suggested value range – Agree?						Alternative suggestions for different pipe diameter ranges or specific pipelines?			
	Value	Yes	No	Value	Yes	No	Value range		Internal diameter range mm	
Roughness	0.015			0.045						
Efficiency	0.95			1.00						
Friction factor	GERG			N = 5						

Comments

4.0 Valves

In general valves have not been included in the model. A couple of valves have been added to demonstrate principle only. It is assumed that due to the overall uncertainty in many detailed aspects of the model that valve losses can be absorbed into general pipeline losses. Please respond to Table 6 below.

Table 6
The necessity for valves

For the objectives of the model valves are not essential – agree?	Yes		No	

Comments

5.0 Regulators

The model does not include regulators at present but the software has the capacity to include them. Does your organization consider that these are essential to obtain useful interpretations from the model? Are there specific locations or facilities where regulators should be included? If so what would be the prime function of the regulator and its operating range? Please respond to Table 7 below.

Table 7
The requirements of regulators

Regulators		**Yes**	**No**
Regulators are considered necessary in the model:-			
Necessary locations for regulators are :-	Storage fields		
	Compressor stations		
	Off-takes		
	Cross border stations		
	Other		

Comments

6.0 Compressor stations

Compressors are a key element in the performance of the model and it is therefore important to include some basic information on the detail of the stations. A diagram representing a compressor station used in the model is shown in Figure 1 below. Please review Table 8 on the following page and complete as many details as possible (the first row provides an example) as appropriate. Further explanation is provided below.

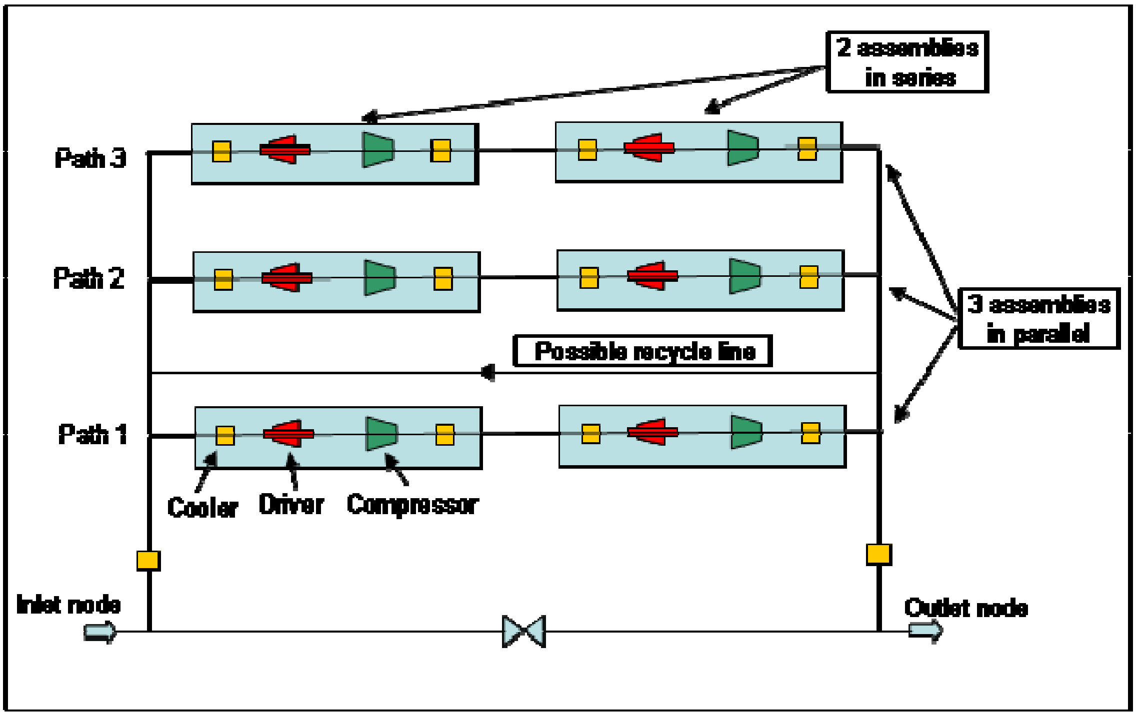


Figure 1: Layout of example compressor station

6.1 Driver fuel

The fuel used for all drivers in the model is given by a polynomial equation. Alternatively a simple proportional value could be used as indicated below. Please indicate in Table 8 your choice and provide values of representative constants that could be used in the model. Fuel consumption is either (for power output in kW):-

A = Nominal fuel rating - Qfuel = A (million cubic meters/kw/hour) and provide a value for A in Table 8
or:-
B = Polynomial fuel rating - Qfuel = $B_0 + B_1 \times Power_{out} + B_2 \times Power_{out}^2$.
Please specify B coefficients in the comments box of Table 8.

In the current model values are:- $B_0 = 638.4166\ m^3/kW\text{-}hr/kW$
$B_1 = 0.013437\ m^3/kW\text{-}hr$
$B_2 = 0.000091\ m^3/kW\text{-}hr\text{-}kW$

or :-
C = Other. Please explain in the comments box.

6.2 Compressor model

The model allows selection of many types of compressor unit. A simple mainly theoretical form has been used in the current model, although full compressor maps could be included if considered essential in the future.

$$P = Q_s \times Z \times [K_1 \times (P_d/P_s)^{K_3} - K_2] \ldots\ldots\ldots\ldots\ldots \text{(iii)}$$

Where:-

P is the output power in kW
Q_s is the flow rate in millions of cubic meters per hour (mm^3/hr)
P_d is the absolute discharge pressure in bar
Ps is the absolute suction pressure in bar
Z is the gas compressibility factor (taken as 1)

Values for the "K" coefficients were taken again from the SynerGee literature example and in metric units are as follows:-

$K_1 = 121927.1\ kW/m^3/hour$ $K_2 = 121663.5\ kW/m^3/hour$
$K_3 = 0.231$ [ratio of {(n-1)/n} where n is the polytropic exponent = 1.3]

Table 8: Compressor station details

Compressor station		Total installed capacity	Minimum system supply & maximum system discharge pressures	Overall Station Pressure loss	Numbers, ratings (MW); Compression Ratios (CR); Transit capacity ($10^6 xm^3$/hour); Driver & Compressor details for turbo sets											Series or parallel arrangement with other units
										Driver				Compressor units		Identify arrangement &/or add a diagram if appropriate
											Fuel					
Unit	Name				Ref. Letter	No. of Units	Rating	CR	Transit capacity per unit	Type	Type Gas/ Electric	Source Input/ external	Consump - tion Type*	Type	Maximum discharge pressure	
No.		MW	Bar	Bar			MW		Mm^3/hr				$m^3/kW/hr$		Bar	All parallel
1	Example	64	50/75	0.5	A	4	6	1.2	0.5	Turbo	Gas	Input	A: 40	Turbo	63	Each in series with an A unit
					B	2	10	1.3	0.6	Turbo	Gas	Output	B	Turbo	77	All parallel
					C	3	4	1.25	0.3	Recip.	Gas	External	A:40	Recip.	58	Two parallel; 1series with A
					D	1	8	1.3	1.0	Turbo	Electric	External	B	Turbo	60	1 in parallel
-	Totals	-	-	-	-	10	64	-	5.1	-	-	-	-	-	-	-
2																
3																
4																
5																
6																

Comments related to Table 8

6.3 Compressor station – general assumptions

For the current model a number of assumptions have been made. Please review Table 9 and indicate the position in your country.

Table 9
Assumptions used in current station modelling

	Assumptions	Agree? Yes	No	Comment - or refer to letter a, b, c, etc.
1	All assemblies are currently in parallel (multiple paths)			
2	All paths only have one driver / compressor assembly			
3	All stations have same pipeline “yard” losses of 0.3bar for each of both the inlet and outlet nodes			
4	All drivers are gas powered			
5	All drivers take gas form the inlet node			
6	All drivers use a polynomial fuel equation			
7	All compressors are turbines			
8	All compressors use the same theoretical form of power/flow equation as detailed in equation (ii)			
9	Control of the station is from the discharge node pressure			
10	A full compressor map is not required			

Comments
a.
b.
c.

7.0 Storage

Storage provides a key measure of maintaining supply under adverse conditions and must therefore be included in the model.

7.1 Short term storage

The objective of the model is to examine longer term issues of criticality. Therefore the model does not provide for any short term storage (1 or 2 day) such as from high pressure bullet stores or low pressure gas holders. The model does calculate line pack that could be utilized in the short term, but meaningful lower limits of pipeline operating pressures would need to be defined.

7.2 Storage fields

At present the model includes a number of storage fields viz:- 7 in the Czech Republic, 5 in Hungary and 1 in Slovakia. The capacities and maximum delivery rates have been calculated from open source data to give daily flow rates and the availability of the store in days as shown in Table 10. No compressor station or regulator is included with the fields and the interest at present is simply to use the maximum outputs from the stores under worst case conditions. Since no data is available on the control details of the stores the model assumes values for the shut-in pressure and the open flow coefficient – the latter being set to provide the maximum flow. The main assumption is that the fields follow the standard equation given in (iii) below:-

$$Q = C_o \times F \times (P_f^2 - P_d^2)^n \;\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(iii)}$$

Where:-

Q = Flow rate (mm^3/hr)
C_o = Open flow capacity coefficient ($mm^3/hr/Bar^2$)
F = Field utilization coefficient
P_f = Field shut-in pressure (Bar)
P_d = Delivery pressure (Bar)

Table 10
Data used for storage facilities

Data source	Country	Region	Store type	Store Name	Working capacity mm^3	Delivery Rates Max. mm^3/hr	Delivery Rates Number days	Delivery Rates Model mm^3/hr
IEA 2002	Czech Republic	Jihomoravsky	Field	Uhrice	100	0.25	16.7	0.249
				Dolni Dunajovice	700	0.50	58.3	0.500
				Tvrdonice	487	0.29	70.0	0.290
		Stredocesky	Field	Haje	57	0.25	9.5	0.220
		Severomoravsky	Field	Tranovice	228	0.10	95.0	0.100
				Stramberk	435	0.25	72.5	0.249
			Aquifer	Lobodice	140	0.13	44.9	0.128
		Totals			2147	1.77	367	1.736
HEO 2006	Hungary	Bacs-Kiskun	Field	Zana-Nord	1300	0.88	61.9	0.826
		Hajdu-Bihar		Hajduszoboszlo	1590	0.80	82.8	0.749
		Zala		Pusztaederics	330	0.11	122.2	0.108
		Bekes		Kardoskut	240	0.10	96.0	0.086
		Csongrad		Maros-1(Algyo?)	150	0.09	71.4	0.085
		Totals			3610	1.98	434	1.854
TEN-E Oct.05*	Slovakia	Zapadoslovensky	Underground	Lab	2000	1.0	83.3	0.977

* NOTE: It is known that the "Lab" store in Slovakia is leased to the Czech Republic. The pipeline route also feeds many other off-takes in Slovakia. The known input flow rate of $0.2mm^3/hr$ to the Czech Republic has been added via the Mokry PS entry point (Node 62) as a discrete source, whilst the Lab store output has been reduced to $0.8mm^3/hr$.

For your country, if the data in Table 10 is incorrect please update by providing data in the table below:-

Country	Region	Store Type	Name	Working Capacity mm^3	Delivery rate mm^3/hr	Comment

Please also respond to the general questions in Table 11.

Table 11
Assumptions for storage fields

	Assumptions	Agree? Yes	Agree? No	Comment - or refer to letter a, b, c, etc.
1	The shut-in pressure for all fields is taken as 100Bar			
2	The open flow coefficient for all fields is taken as 0.7			
3	The field utilization coefficient for all fields is taken as 1.0			

Comments
a.
b.
c.

8.0 System pressures and flow rates

There is no current open source data on system pressures so assumptions have had to be made. GIE offer a set of maximum flow rates at cross-border points. The model has been set to provide these maximum flow rates out of the system to Germany and Austria and in an iterative manner the inlet pressures to the system have been set to provide flow rates from the Ukraine to both Slovakia and Hungary that enable a solution to be obtained. The resulting import supply flows are then generally larger than the maximum flow rates provided by GIE (see Summary of Results- section11). System pressures are currently created by setting values at the compressor stations. At present the model does not generate all the maximum flows at the same time and this might reasonably be expected and the approach adopted by no means provides a unique solution as pressures at various points in the system can be varied. Under normal circumstances, gas is supplied according to contractual arrangements between countries and operators and this model may not then be appropriate. However, under extenuating circumstances it appears that recourse to supplying maximum flow rates must be considered by operators. Any comments on the overall strategy would be welcome.

Comments

9.0 Production sources

Little data has been found on production facilities or their locations within the three countries considered in the model but it is clear that the overall contribution to annual load in two cases at least is very moderate amounting to less than 1.5% of annual consumption. Table 12 shows the assumptions used in the current model. Please review and if you can supply improved data please complete the following table and add any further comments.

Table 12
Assumptions on location & flow rates of production facilities

Country	Production per year (from Eurogas 2005 data)		Flow mm^3/hr	Arbitary number & production locations chosen for model
	PJ	As % of annual consumption		
Czech Rep	4.8	1.4	0.01441	1 near Stramberk
Hungary	108.4	19.3	0.32545	The 5 storage fields each of 0.065
Slovakia	3.6	1.5	0.01081	1 near Láb

	Assumptions	Agree?		Comment
		Yes	No	- or refer to letter a, b, c, etc.
1	The locations are adequate for the model			
2	The flow rates used are adequate for the model			
3	Production flow rates are sustainable 24(hours)/ 7(days)			

Country	Production site Location co-ordinates	Available capacity	Max. hourly flow rate	Max. time supply can be maintained	Supply pressure
	Latitude/ Longitude	mm^3	mm^3/hr	Hours	Bar

Comments

10.0 Distribution of National consumption

The following section reviews the issues that have been addressed in arriving at a value of gas demand required at the off-takes of the transmission systems. It would probably be inappropriate at this point in time to provide a complete breakdown of the final values used in the model. A summary of the final data is provided at the end of this section. The objective is to seek comment on the approach and to obtain a reaction on the end results achieved. The base values may be incorrect but perhaps the proportional distribution may be acceptable. It is realised that the timing allocated to loads will significantly affect flow rates and therefore this topic is equally as important as other issues in the model. Annual consumption data for countries is available from several sources together with the distribution of use between the primary customers, namely:-

Domestic	Industrial
Commercial	Power generation

A number of assumptions have been made in the model to date with regard to the distribution of consumption with regard to several aspects as provided in the presentation. Please comment on these issues below.

Table 13
Issues concerning the distribution of loads

	Issue	Comment or continue in box below
1	Temperature dependency of loads	
2	Time loads are sustained	
3	Distribution of domestic loads	
4	Distribution of industrial loads	
5	Distribution of loads by region	
6	Number of off-takes per region	

The end result may be considerably different from reality. Please comment in Table 13 on these issues and whether such information would be considered to be confidential to your organization. Is there an alternative solution to this issue?

Comments
a.
b.
c.

10.1 Load and peak demand

The model is intended to provide information about the consequences of a sustained non-availability of a critical infrastructure. Peak demand is therefore considered to be not the peak day demand of a whole year but the average demand sustained over perhaps 2-3 weeks in a peak month. Peak demand in the model was calculated from the annual demand profiles from year 2000 data and annual data for 2005. Further, it is currently assumed to be for the same period (or part-month) for all countries in the model. Finally in the case of Slovakia, the data is derived from equations fitted to the data based on the normalized annual load profile of the other two countries. (Please refer to the presentation material). Please comment in Table 14 below.

Table 14
Load profiles

	Issue	Agree?		Comment or continue in box below
		Yes	No	
1	Annual load profiles remain similar			
2	The profile is acceptable for the model			
3	We could supply more recent profiles			
4	The demand amount is too great			

Comments
a.
b.
c.

10.2 Population & number of gas customers

Assumptions about population and dwelling distribution have been made in the model and these link very closely to the distribution of load. Data was available on the number of dwellings by region but a basic assumption made is that customers are distributed proportionately by dwelling and region. Additionally there was no data immediately available on the distribution of industrial load or power generation load by region. The current assumption is that the industrial/power load and number of customers is distributed in the same proportion to the number of domestic customers per region. This may be far from correct and any guidance on the distribution of customers would be beneficial. The presentation material together with the previous Table 13 covers these major issues.

10.3 Summary

The general assumptions discussed in this section resulted in the summary data supplied in the following two tables. Please review these values and provide any comment in Table 16.

Table 15
Summary load data by region

Country	No. of	Population	Area	Dwellings	No. of customers		Consump. (mm3)/hr			No. of
	Regions	No.	km2	No.	Domestic	Ind.	Domestic	Ind.	Total	Offtakes
Czech Republic	8	10,247,504	77,932	4,748,418	2,564,300	173,400	1.831	0.856	2.687	56
Slovakia	8	5,379,455	48,877	1,896,554	1,424,000	1,000	1.045	0.735	1.781	173
Hungary	20	12,088,332	92,782	4,069,820	3,038,000	182,000	3.526	0.904	4.430	164

Country	No. of regions	No. of off-takes	Average No. of off-takes per region	Flow rate/off-take mm^3/hour		
				Maximum	Minimum	Average
Czech Republic	8	56	7.0	0.136	0.015	0.048
Slovakia	8	173	21.6	0.025	0.007	0.01
Hungary	20	164	8.2	0.057	0.010	0.027

Table 16
Comments on load distribution

Issue		Agree?		Comment or continue in box below
		Yes	No	
1				
2				
3				
4				

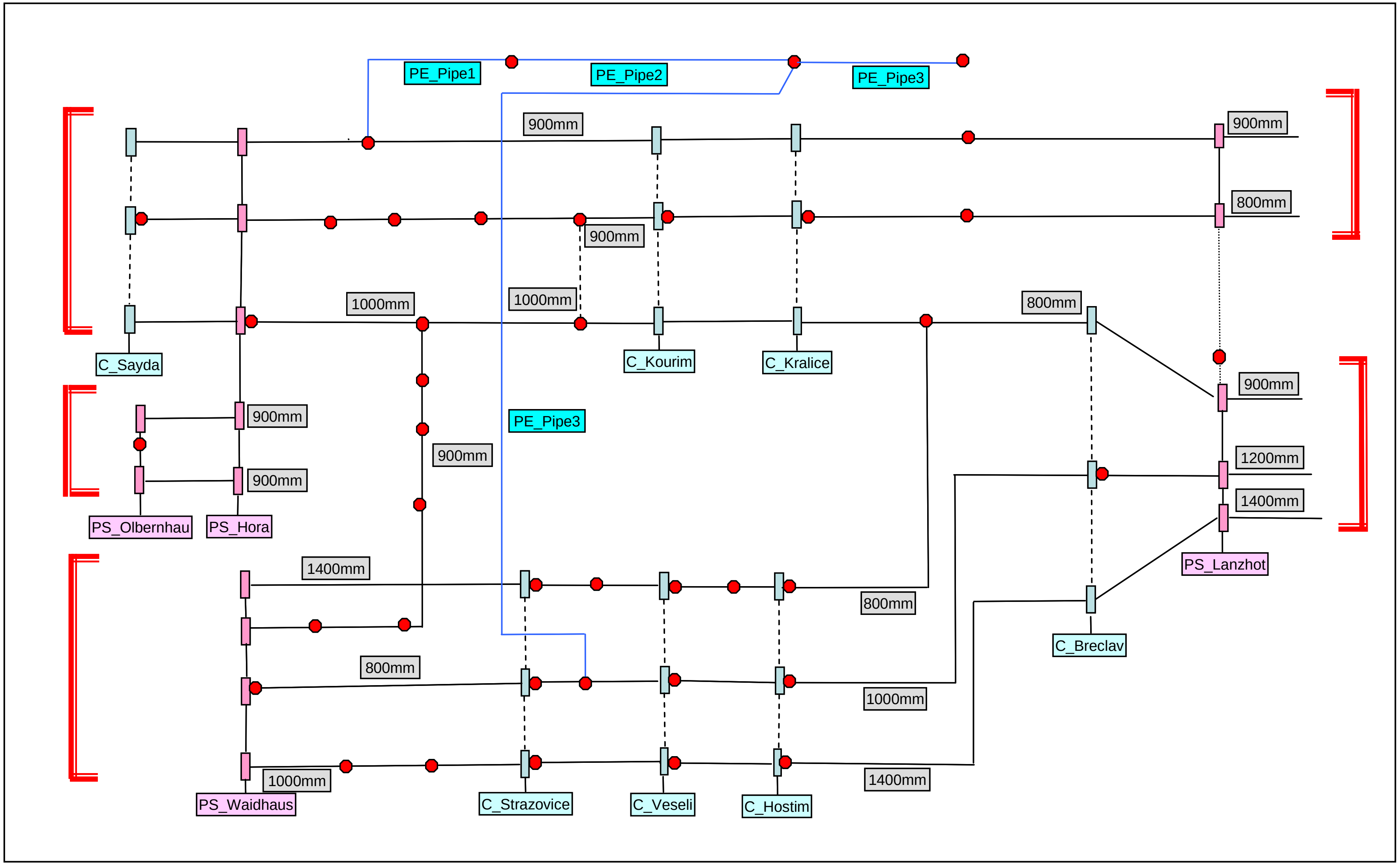
Comments
a.
b.
c.

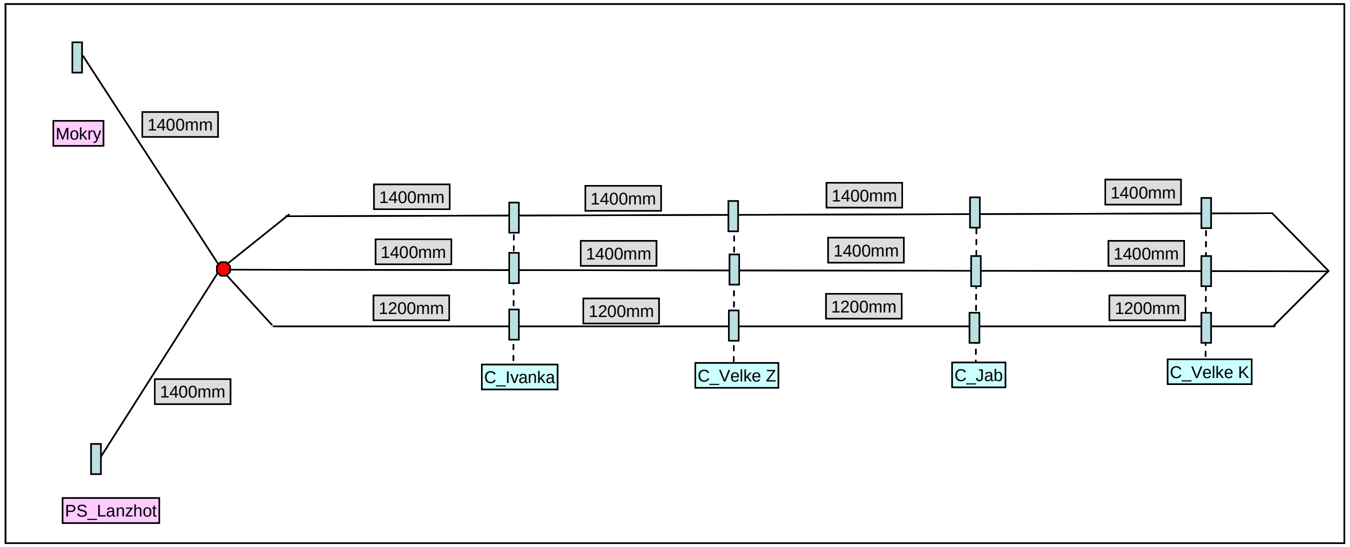
11.0 Summary of results

Figure 2 provides the key pressures and flow rates generated in the current version of the model and Table 17 summarizes the major data inputs and provides a flow balance of the whole model. The border crossings in Figure 2 are lettered A – H and these are referenced in Table 17. The values may be far from your normal operating conditions. Please provide any comments on these results in the comment boxes.

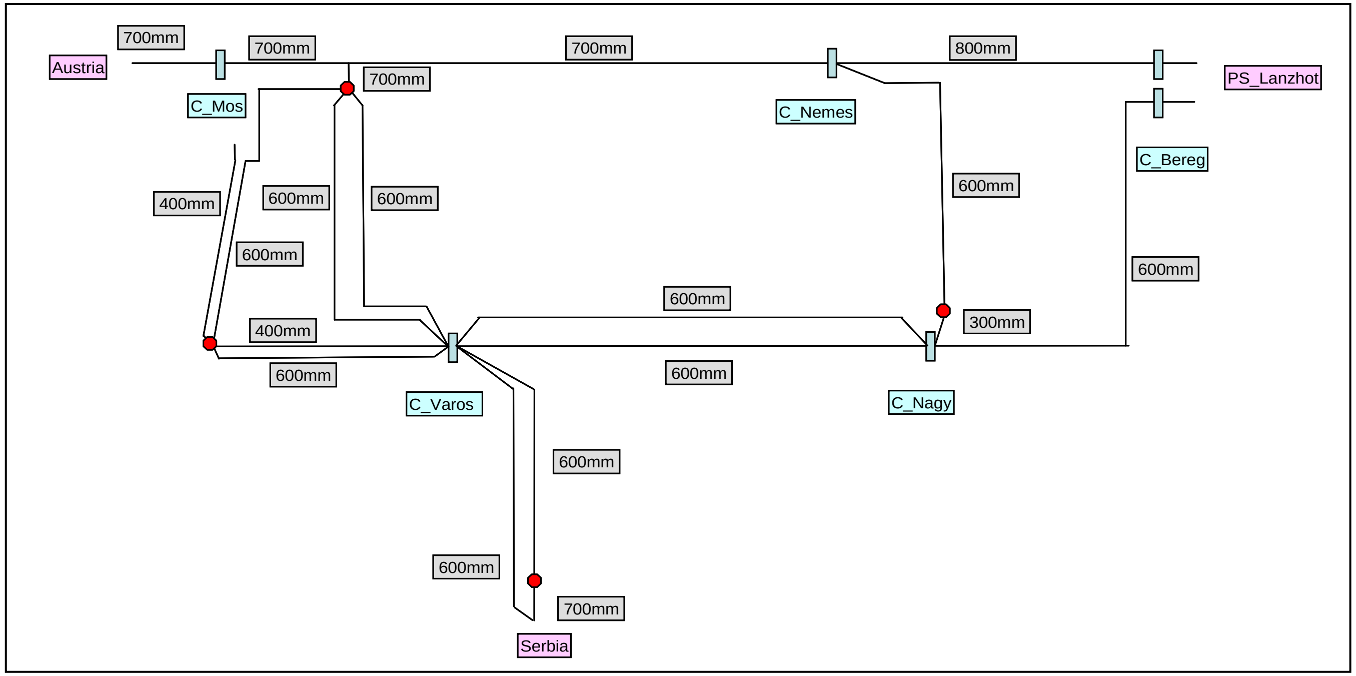
Also included in support of the questionnaire were Figure 21, Table 17 and Appendix V from this report with requests for comments together with the schematic diagrams shown below.

Czech Republic main transit route – Multi-pipeline ROW - external pipe diameters





Slovakia
Main ROW
multi-pipeline
corridors
- external
diameters



Hungary
Main ROW
multi-pipeline
corridors
- external
diameters

12.0 Conclusion

Thank you very much for finding the time for reviewing the issues regarding items that have been used to develop the current model. Your contribution is greatly appreciated. If there are further comments not covered above, please enter in the box below. Feel free to discuss the details further by contacting me via the e-mail address below. All correspondence will be treated as confidential.

Final comments

Russell Pride

Institute for the Protection & Security of the Citizen (IPSC)
Traceability & Vulnerability Assessment Unit
Joint Research Centre (Ispra)
European Commission
T.P.361
21020 Ispra (VA)
Italy

Russell.pride@jrc.it

Phone: 0039 0332 78 6385
Fax: 0039 0332 78 5145

European Commission

EUR 23434 EU – Joint Research Centre – Institute for the Protection and Security of the Citizen
Title: A Gas Pipeline Model to Support Critical European Energy Infrastructure Assessment
Author(s): Russell Pride
Luxembourg: Office for Official Publications of the European Communities
2008 – 73 pp. – 21 x 29.7 cm
EUR – Scientific and Technical Research series – ISSN 1018-5593

Abstract

Introduction

In the context of European Policy, in December 2005, the Council called upon the European Commission (EC) to make a proposal to develop a Directive on the identification and designation of European Critical Infrastructure (ECI). The original focus on terrorist threats later evolved into an all hazards approach. The severity of consequences and European dimension are to be assessed on the basis of Public, Economic, Environmental and Psychological effects, whilst owners/operators of ECI need to establish a "Sector" specific operator plan, including identification of assets, risk analysis and countermeasure prioritization. The EC is developing cross-cutting criteria to support the process of ECI identification on the basis of severity of consequences of disruption or destruction of the infrastructure. For the "Energy Sector" an improved understanding of the criticality of gas supply routes and infrastructure is desirable and it is anticipated that a model of the transnational gas pipeline network would assist in the process of assessing the usefulness of the cross-cutting criteria applied to this sector.

Building on previous work undertaken within the SARES Action, a methodology is being developed using detailed gas pipeline network modeling software to help identify elements of a network that may be considered to be critical. Gas has a key role in the energy supply future of the EC, with growth anticipated to rise from currently one fifth, to one third of total energy supply within the next 25 years, most of this increase for electricity generation. Up to 66% of gas may be derived from imports, these being essentially supplied through pipelines traversing the Russian Federation and the Commonwealth of Independent States, although an increasing quantity will be provided by sea transportation of LNG (Liquid Natural Gas). Market forces in general dictate what is commercially acceptable in terms of hardware infrastructure investment for meeting demands, but with an aging pipeline population the security and reliability of pipeline transmission gas supplies is seen as a key issue for Europe.

Pipeline models

Following a review of commercially available software for pipeline modelling a package from Advantica called SynerGee was purchased for evaluation. This can utilize underlying GIS pipeline route maps and hydraulically model all the key components of a pipeline system, from valves and regulators to storage fields and compressor stations. Some data previously collected for developing an Excel spreadsheet model "GENERCIS", has been used to populate the model, but data from other sources such as Platts has provided the basic GIS background pipeline layout.

Current status

The Czech Republic was initially selected for compiling a demonstrator of the functionality of the approach. In addition, connecting networks and infrastructure were then introduced for the adjacent countries of Slovakia and Hungary. For all three countries the components of the Trans-National transmission pipeline network and the National high pressure network have been introduced into the model, but only generic details of items such as compressor stations and storage fields have been used. Following analysis of the model and assessment of its potential usefulness it was then demonstrated to the countries gas network operators in a workshop. The operators were generally supportive of the approach adopted and as a result more accurate details of the components may be made available through their subsequent completion of a questionnaire.

Conclusion

The development of a three-country gas network model using open-source data has been successfully demonstrated. The usefulness of the model in assessing cross-cutting criteria for the proposed European Directive on critical infrastructure may now be progressed.